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Banana Nutrition

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1. Introduction

The banana is an important food crop for man, especially in the tropics. The world produces about 41 million tonnes of bananas each year but most of them are locally consumed (Table 1). In 1986 about seven million tonnes entered the world banana trade *[18]*. Almost eighty percent of the world's export bananas are produced in the Americas (Central, South and Caribbean). In terms of world trade in fruit, bananas are second only to grapes. The banana is produced in the tropical and subtropical regions and a supply is available to the customer all through the year.

Since bananas are grown from between latitudes 33° north and south and on a wide range of soils, the mineral nutrition of the crop has attracted much attention. In a recent bibliography 803 references were recorded up to 1978 *[50]*. The subject was reviewed in the 1960s by *Champion [8]*, *Simmonds [84]*, *Freiberg [23]* and *Twyford [103]*. Since then some five hundred articles have been published relating to banana nutrition. It is not our intention to review all of these but rather to draw attention to the main advances which have been made since then. *Martin-Prével [64]* has recently reviewed aspects of leaf analysis in bananas.

Until the mid-1960s nutrition research on bananas had concentrated on the description of symptoms of nutrient imbalance and the conduct of field experiments comparing response to rates of applied fertilizer on a range of soil types.

Table 1. Production, export and import of bananas by continent and top nine countries in each category in 1986 (in 1000 tons, after *FAO [18]*).

	Production		Export		Import
Asia	14 133		1004		1044
L. America	20 426		5678		222
N. America	4		–		3116
Africa	5 193		195		13
Oceania	1 113		4		55
Europe	430		432		2902
World Total	41 299		7313		7352
Brazil	7 563	Ecuador	1366	U.S.A.	2816
India	4 748	Costa Rica	882	Japan	765
Philippines	2 303	Colombia	857	Fed. Rep. Germany	635
Ecuador	1 930	Philippines	856	France	454
Indonesia	1 900	Honduras	800	Spain	357
Mexico	1 900	Panama	586	United Kingdom	343
Thailand	1 596	Spain	400	Italy	339
Viet Nam	1 381	Guatemala	331	Canada	301
Colombia	1 300	France	301	Argentina	129

During the last fifteen years there has been an attempt by numerous workers to understand more clearly the part played by nutrients in the growth and development of the plant. Field studies of fertilizer response are still being conducted, but attempts to relate nutrient concentrations in the soil and the plant to yield have complemented this work *[54, 111, 112]*.

Analysis of plant parts for mineral elements and the attempt to set standards for interpreting leaf analysis data came to the fore in the late 1960s and early 1970s *[68, 76]*. However, each researcher approached the problem differently, probably reflecting a lack of unifying concepts in the understanding of the growth and nutrition of the banana. *Martin-Prével* initiated the formation of an *International Group on Mineral Nutrition of the Banana* and this resulted in a suggested *International Reference Method* for sampling in banana fertilizer experiments *[61, 62]*.

Other work has attempted to provide some understanding of the nutrition of the banana in relation to growth und nutrient supply. *Martin-Prével et al. [68, 76]* studied the nutrient uptake of the plant at several growth stages and at six sites in the French Antilles. *Twyford and Walmsley [106, 110]* conducted similar experiments in the Windward Islands on high and low yielding sites. While these experiments lacked control (climate and soil differed from site to site), they provided an excellent basis for a rationale of banana fertilization as well as an understanding of nutrient uptake in the field.

Some long-term sand culture studies have been conducted in Israel *[42]* and Australia *[98]*, mainly aimed at understanding the K nutrition of the plant. These experiments have provided a data base for assessing sampling techniques and the interpretation of leaf analysis data from the field. They have been especially useful in establishing relationships between nutrient concentrations in leaves, the nutrient solution and the effects of environment on these relationships *[99]*. *Martin-Prével [60]* explored the physiology of nutrient deficiencies in bananas, especially the role of K and P. These data contribute to an understanding of plant behaviour and help explain the growth of the plant in the field. *[63]*.

2. Botany

The banana is a giant herb with an underground rhizome (commonly called a corm) which is surmounted by a growing point. Lateral buds produce suckers which together with the parent corm make up the stool or mat. The stool consists of single-axis plants representing up to three visible generations. Each growing point produces about 40 ± 10 leaves before it becomes reproductive. The ontogenetic sequence of vegetative growth, flowering and fruit growth is not set seasonally as in citrus, pome or stone fruits. In the plant crop, the growing point originates from an apical or lateral bud in the planting material. Suckers may commence to grow after the parent has produced about 12 leaves *[93]*. In the subtropics or at high elevation only 26 ± 2 leaves are produced annually *[91]*, the crop cycles being extended to 1.5–2.0 years. In general, once the plant crop harvest commences the plantation enters a phase of almost continuous fruit production, although the harvest distribution can show large seasonal variation.

3. Climatic requirements

The rate of appearance of new leaves is largely governed by temperature, as is the rate of fruit growth, provided that water and nutrient supplies are adequate. The optimum temperature for leaf emergence is about 25–30 °C, the upper and low limits being about 40 ° and 10 ° respectively, depending on cultivar (Figure 1). In tropical environments one crop cycle may be as short as seven months. Bananas are sensitive to low temperatures. Temperatures below 10 °C cause chilling and irreversible frost damage occurs when leaves are exposed to –2 °C for 10–15 minutes *[83]*.

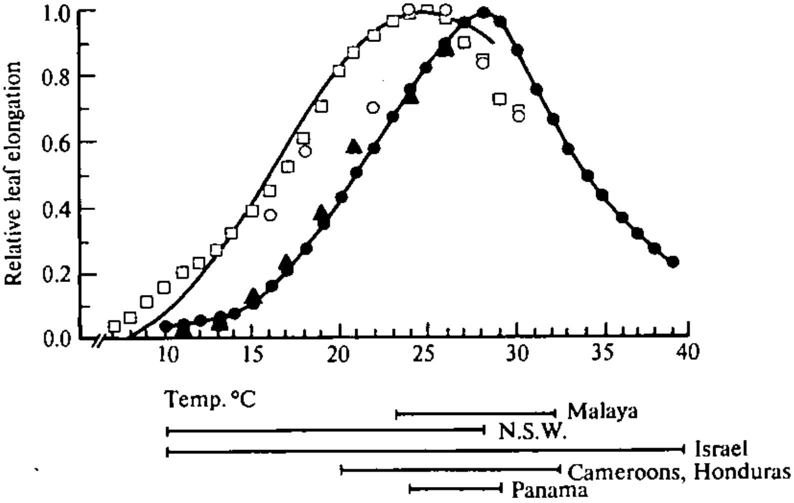


Fig. 1. Relationship with temperature (°C) of the relative leaf elongation rates of banana leaves for varieties 'Giant' (● *[25]*) 'Dwarf Cavendish' (▲ *[33]*) and 'Williams' (○ □ *Turner*, unpublished). Curve fitted to 'Williams' data by least square method. The mean minimum-mean maximum temperature range of some banana production areas is shown.

The net assimilation rate of the banana leaf canopy is broadly related to total solar radiation *[93]*, but shading down to fifty percent of full sunlight does not reduce yields in the tropics *[79]*.

Wind influences crop water use, tears the leaf laminae and at high speeds (about 30 m/sec) destroys the plantation. *Green [32]* considered it to be the most widespread scourge of banana plantations. Wind breaks and/or props are widely used to overcome deleterious effects, but data on the influence of low wind speeds on growth and yield of the banana are few. Leaf tearing increases the photosynthetic/water use efficiency of leaves of *Musaceae* and reduces heat stress under high radiation loads *[89]*. In situations of low wind speed (<3 m/sec), where little or no leaf tearing occurs, leaf folding will achieve the same results as tearing *[94]*.

Bananas are grown in areas of widely varying relative humidity, from arid climates to the humid tropics. High humidities are thought to be required but bananas are grown successfully in arid areas. Precise data on the influence of humidity on growth and yield are not available.

Early work on banana nutrition reflected a concern for the effects of climate on growth and yield, and responses to nutrients were interpreted within the context of climate and plant ontogeny *[88]*. This premise still stands and is fundamental to an understanding of the nutrient demands of the crop, the seasonal occurrence of nutrient deficiencies, and the application of fertilizers for high yields.

4. Soil requirements

Bananas are grown successfully on a wide range of soils although little experimentation has been done to define accurately the soil conditions necessary for high yields. Some soils in Central America produce 50–60 t/ha/yr of high-quality fruit for export. These soils are deep, fertile, well-drained loams and light clay loams. Yield may be depressed in soils with a high clay content or where a compact or gravelly layer occurs at 30–60 cm depth *[87]*. Poor drainage could be a problem in some of these situations.

The root system of the banana is not inherently shallow (although this is widely accepted) but its depth is a function of soil conditions. Shallow water tables mean shallow root systems, deep water tables allow roots to penetrate to 1.5 m or beyond. Irrigation methods influence root distribution – under drip irrigation the root system is less extensive than where flood or sprinkler irrigation is practised.

The effect of soil pH on banana production has not been widely studied but bananas will grow on soils with pH extremes of 3.5 to 9.0, although pH of 5.5 to 8.0 is probably the usual range. In Guinea pH is positively correlated with banana yields *[9]*, soils with pH 4.5 having about half the yields of those with pH 6.0. *Godefroy et al. [31]* applied lime to a soil of pH 3.5 to 4.0 at rates of up to 24 t/ha and studied physical and chemical changes in the soil as well as banana productivity. Soil pH was changed from 3.5 to 6.7 but total yield was not significantly changed over three crop cycles (Table 2). In the Canary Islands soil pH over the range 4.4 to 8.2 is negatively correlated with pseudostem circumference *[26]*, but on average a reduction of only 4% in circumference occurs over the whole range. These data support the hypothesis that bananas are tolerant to a wide range of soil pH. At high soil pH the supply of trace elements may be restricted.

Table 2. The effect of lime application to a peat soil on pH and banana yields in Ivory Coast *[31]*.

Treatment t/ha	pH*	Yield (t/ha) Crop Cyle 1	2	3	Total
0	3.4	43.8	48.0	39.0	130.8
3	4.2	43.4	47.9	41.6	132.9
6	4.7	43.4	47.8	42.3	133.5
12	5.9	46.2	48.6	44.1	138.9
24	6.7	44.3	49.5	43.3	137.1
		NS	NS	NS	

* — after two years
NS — no significant difference

4.1 Soil management and cultivation

Most areas are planted with very limited soil preparation or with shallow ploughing. Deep ploughing to disturb impermeable layers had a beneficial effect on productivity (Table 3) *[28, 113]*. Fallowing after deep ploughing reduced the nematode population *[113]*. Soil cultivation is not usually practised in ratoon plantations and weeds are controlled by means of herbicides, machette or hoe. Sometimes clean cultivation by tractor is used in young plantations.

Table 3. The effect of ploughing on productivity (t/ha) of bananas in Israel *[113]*.

Treatment	Control	Subsoiler	Deep Ploughing
Depth of cultivation (cm)	35	45—50	60—65
Plant crop	8.0	9.2	11.9
First ratoon	21.9	30.6	38.2

4.2 Intercropping and rotation

Intercropping is traditionally practised in many African and Central American countries. Some of the crops grown with bananas and plantains are maize, yam, cassava, rice, beans and sugarcane. The nutrient relationships between plants in intercropping systems has not been investigated. Recently, the yields of plantain were examined when cocoyam, maize and cassava were used as intercrops *[14]*. Fertilizer application was adjusted accordingly (Table 4).

Bananas for export are sometimes grown under coconuts in the Caribbean *[79]* and in Australia, Israel and the Canary Islands with avocados. In the latter case the bananas are used as the interplant crop and they are removed as the avocado trees increase in size. Since the fertilizer needs of avocados are relatively small, the banana fertilizer programme need not be changed.

Crop rotation is not normally practised in banana culture except for the control of some diseases and nematodes *[87]*. In Israel rotation is a common practice with legumes, cereals and deep ploughing in between two cycles of bananas.

Table 4. Intercropping of plantains in Africa. Yields and total fertilizer input *[14]*.

Crops	Plantain			
	alone	+ cocoyam	+ maize	+ cassava
Plantain Spacing (m)	2 × 3	2 × 3	2 × 3	2 × 6
Yield of plantain (t/ha)	17.5	18.2	18.7	9.8
Total economic yield (t/ha)	17.5	21.2	24.2	23.4
N (kg/ha/yr)	250	250	330	205
P (kg/ha/yr)	250	250	310	185
K (kg/ha/yr)	250	250	310	185

5. Water requirements

Water use by bananas is a function of supply (rainfall or irrigation), soil water holding capacity, demand (potential evaporation) and plant factors such as leaf area index and leaf resistance. In the tropics measured evaporation, E_a, was 1.2 to 1.4 times class A pan evaporation, E_p, for well watered soil with complete canopy *[27]*. In the subtropics, under drip irrigation the ratio may be as low as 0.9 E_p in mid-summer *[52]* but under flood irrigation it is much higher. When growth stops in the winter in the subtropics, water use is very small even though a considerable amount of leaf area may be present *[94]*.

Irrigation is an important factor when considering nutrition but the research on the relations between them is very limited. Irrigation water may be used as a carrier for plant nutrients *[52]*, for leaching salts from the profile in dry areas and for moving surface applied fertilizer into the root zone. If water supply limits growth then the uptake of nitrogen (see section 6.1) and perhaps of other nutrients is restricted. In a recent study in Israel a reduced water supply reduced the P concentration of leaves *[49]*. The method of water application can alter the concentrations of nutrients in plant tissues and may be important in the overall nutrition of the crop. The concentration of K and P in the petiole is reduced by drip irrigation, compared with sprinkler or flood irrigation (Table 5). Applying water using the drip system significantly reduces iron chlorosis.

Table 5. The effect of irrigation method on K and P concentrations (% d. w.) in petiole 7 of 32 plantations of Dwarf and 27 plantations of Williams bananas in Israel *[49]*.

Element *	Variety	Irrigation system		S. E.	Sig.
		Sprinkling	Drip		
K	Williams	4.3	3.5	0.12	0.05
	Dwarf	5.8	3.5	0.17	0.01
P	Williams	0.11	0.09	0.006	0.05
	Dwarf	0.12	0.10	0.004	0.05

* N concentrations were unaffected

6. Nutrient requirements and effects

For growth and fruit production bananas require high amounts of mineral nutrients which are often only partly supplied by the soil. To establish a crop yielding 50 t/ha/yr of fresh fruit, about 1500 kg K/ha/yr may be extracted from the soil. Amounts of other nutrients found in field grown plants at harvest are (rounded; in kg/ha/yr): N–450; P–60; Ca–215; Mg–140; Mn–12; Fe–5; Zn–1.5; B–1.25; Cu–0.5 *[106, 110]*. Thus large quantities of nutrients have to be replaced in order to maintain soil fertility and to permit the continuous production of high yields. This is achieved by applying organic manure and/or more efficiently by mineral fertilizers which supply nutrients in a concentrated and readily available form.

The overall requirement of nutrients can be estimated from analysis of the whole plant and estimated plant growth *[57, 58, 106, 110]*. The grower

Table 6. Summary of deficiency symptoms.

Age of leaf	Symptoms on blades	Additional symptoms	Element
All ages	Uniform paleness	Pink petioles	N
		Midrib curving (weeping, drooping)	Cu
Young leaves only	Whole leaf yellow-white		Fe
		Thickening of secondary veins	S
	Streaks across veins	Leaves deformed (blade incomplete)	B
	Stripes along veins	Reddish colour on lower side of youngest leaves	Zn
	Marginal chlorosis	Thickening veins. Necrosis from margins inward	Ca
Old leaves only	Sawtooth marginal chlorosis	Petiole breaking. Bluish-bronze colour of young leaves	P
	Chlorosis in midblade, midrib and margins remain green	Chlorosis limit not clear. Pseudostem disintegrating	Mg
	Blade dirty yellow green		Mn
	Yellow-orange chlorosis	Leaf bending. Quick leaf desiccation	K

needs to know the ability of the soil to meet these requirements and whether supplementary fertilizer is needed. Two approaches have been adopted to solve this problem. In one approach field experiments can be established on a range of soil types. *Twyford [103]* has reviewed many of these and many more have been conducted since the mid-1960s. Apart from the problems associated with interpreting the results of banana field experiments *[106]*, the results of these trials are dependent upon local conditions of climate, soil and cultivar. Therefore, the reliable extrapolation of results is limited. In an effort to make the results of field experiments more meaningful, effort has been put into another approach: the analysis of plant and soil, with the aim of estimating the amount of fertilizer required to optimize yields *[41, 58, 112]*.
Symptoms are useful in diagnosing nutrient imbalance and these are summarized for all nutrients in Tables 6 and 7.

Table 7. Summary of excess symptoms *[1, 10, 19, 82, 87]*.

Symptoms on	Descriptions of symptoms	Element
Petioles	Blue	Mg
Leaf	Irregular chlorosis followed by necrosis	
	Marginal chlorosis followed by necrosis	Na, B
	Marginal blackening followed by necrosis	Fe, Mn
	Chlorotic striping	As
Fruit	Not filled	
	Not filled	Cl
	Weak bunch, widely spaced hands	N
Roots	Growth inhibited	Cu

6.1 Nitrogen

Nitrogen is considered a most important element for banana plant growth, being almost universally in short supply, even on the very fertile soils of Central America *[3]*. It is second only to potassium in terms of the amount needed for crop growth *[103]*. Deficiency symptoms appear quickly and soon all leaves are affected. The leaves are pale green in colour, with the midribs, petioles and leaf sheaths becoming reddish pink (Plate 1) *[77]*. The distance between successive leaves is reduced giving the plant a "rosette" appearance. Nitrogen deficiency symptoms are often observed under conditions of poor rooting and of weed competition. The pale green colour of the blade and the inhibited growth are also associated with water shortage and bad drainage.

6.1.1 Nitrogen and growth

In Murray's sand culture experiments, where plants had access only to the N contained within the planting material, the effect on growth was more marked than with any other nutrient. Under these conditions N deficiency more than halved the rate of leaf production, whilst deficiencies of other elements had only a slight effect (Table 8). *Martin-Prével* and *Montagut [68]* outlined the importance of N in banana plant growth and indicated a two-way relationship between N uptake and dry matter production. Since no N storage occurs within the plant, additional N promotes growth, except when other factors limit growth, and then no further N is absorbed. For the banana, the relationship between total dry matter production and total N uptake is a close one, even taking into account different varieties and different environments and soils (Figure 2). The close association between N and dry matter production observed for the whole plant is repeated within the plant where, in the vegetative stage, most tissues contain 1–2% N, except for the leaves which contain about 3% N. Consequently proportional distribution of N within the plant closely follows that for dry matter.

6.1.2 Nitrogen fertilizer practice

In the field, N deficiency is easily corrected by a variety of N fertilizers. However, the management of N nutrition will depend on a knowledge of anticipated response and other factors limiting growth such as climate or other nutrients. In unfavourable conditions, the uptake of N stops and N fertilization is unnecessary. The most commonly used N fertilizers are NH_4NO_3, $(NH_4)_2SO_4$ and urea. The form used will depend on soil pH and on the presence or absence of irrigation, since urea is not recommended for dry land conditions *[103]*. Potassium nitrate is also a very suitable fertilizer for bananas *[53]* especially since it supplies both N and K in the ratio 1:3. Its high expense limits large scale use. Usually about 250 kg N/ha/yr are applied but in some countries up to 600 kg/ha are added.

Urea (up to a concentration of 5%) can be applied to banana leaves as foliar spray and uptake takes only a few hours *[4]*. However, it is impractical on a large scale because of the very high amounts of N required and therefore frequent spraying is needed.

Usually N is applied 3–4 times annually both in the tropics and subtropics *[103]*. Exceptions are where rainfall is very high, or with irrigation, and

Table 8. Number of leaves produced in 158 days and average interval between leaves (Dwarf Cavendish in sand culture after *Murray [78]*).

Element	No. of leaves	Days between leaves
Control	16.5	9.5
−N	7.0	22.6
−P	13.0	12.1
−K	11.5	13.8
−Ca	13.5	11.7
−Mg	14.5	10.9

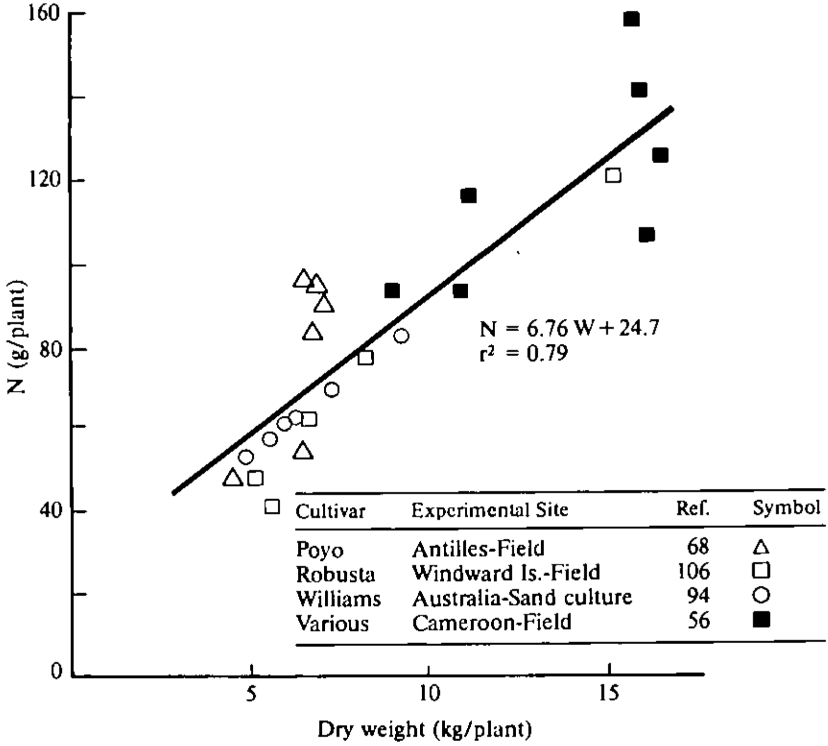


Fig. 2. Nitrogen content in relation to whole plant dry weight.

then monthly additions are required *[14, 39]*. N can be applied in the irrigation water. This method is ideal since N supply can be accurately matched with expected demand. Where slow release fertilizers such as ureaformaldehyde are used, two applications annually appear satisfactory in the tropics, whilst one application in the spring may be sufficient under the subtropical conditions of Israel *[34]*. Factors limiting widespread use of ureaformaldehyde are that, once applied, the release of N cannot be changed and also it is very expensive.

6.2 Phosphorus

The phosphorus requirement of the banana is not large and deficiency symptoms are rarely seen in the field although yield responses to P fertilizer are not uncommon *[13, 111]*. P is a mobile element and is re-utilized within the plant. This would contribute towards the plant's low P requirement *[63]*.

Deficiency symptoms have been recorded in the field in Dominica *[84]* and Guadeloupe *[40]* and in sand culture. Low P supply results in very stunted growth and poor root development. Older leaves have a marginal chlorosis in which purplish brown flecks develop and eventually coalesce to produce a "sawtooth" necrosis. The affected leaves curl, the petioles break, and the younger leaves have a deep bluish green colour *[10]*.

The most rapid phase of P uptake is in the small to large stage (2–5 months of age in the tropics). After bunching, the uptake rate falls to about 20% of the rate in the vegetative phase *[109]*. P uptake is thought to be influenced by Mg supply – low Mg supply reduces root uptake and restricts transfer of P to the tops *[63]*. However, in a sand culture experiment over three crop cycles *Turner [94]* found that low Mg supply reduced whole plant P uptake by 19% but only through its effect on whole plant dry matter (20% reduction). Low Mg supply did not influence the transfer of P to the tops since the proportion of whole plant P retained in the roots was unaffected. Low Mg supply did reduce the concentration of P in the dry matter of the lamina of leaf 3 – also observed by *Martin-Prével [63]* – but it had no effect on the concentration of P in the roots. The contrasting conclusions of these experiments show that caution is needed in making inferences about the nutritional status of the whole plant based on the analysis of one or two plant parts.

The optimum application of P to soil is about 3–4 times greater than that shown to be required by whole plant analysis. This is presumably related to the P adsorption properties of the soils used *[106]*. Red tropical soils have high P adsorption properties. P loss caused by leaching is usually not a problem but recently it was suggested in Israel that P may be leached if drip irrigation is used (see Table 5). Under these conditions frequent P applications may be needed *[49, 53]*.

The most commonly used P fertilizers are superphosphate and rock phosphate applied at the rate of about 100 kg P/ha/yr. It is good practice to incorporate the P into the soil but this is practicable only before planting. In ratoon crops P is usually broadcast, along with other fertilizers. Penetration of superphosphate was found to be directly proportional to application rate. More than 320 kg P/ha/yr was required to obtain penetration to 20 cm *[46]*. Superphosphate can be applied at any time of the year but for more soluble P fertilizers (*e. g.* H_3PO_4) application should be confined to the growing season. In a healthy plantation P application could be made biennially.

6.3 Potassium

Potassium is a key element in banana nutrition. The earliest reference *(1807)* to analysis of banana plant sap showed a high concentration of potassium in the plant *[21]*. This observation has since been confirmed for many cultivars in many countries *[103]*.

Symptoms of K deficiency in the field have been described as "leaf fall" *[55]*, "premature yellowing" *[84]* and "banana yellows" *[73]*. The most universal symptom of K deficiency is the appearance of orange-yellow chlorosis of the oldest leaves and their subsequent rapid death (Plate 2a and Table 6). The life span of the leaf is significantly reduced *[44, 78]*. The midrib curves so that the tip of the leaf points towards the base of the plant (Plate 2b) *[44, 65, 77]*. Other effects of K deficiency are choking (Plate 3), reduced leaf size, delay in flower initiation, reduced fruit number/bunch and hand number/bunch and especially fruit size. These symptoms occur in the field or in sand culture when K deficiency is incipient. Sud-

Captions Photos 1–7 (pages 18 and 19)

Plate 1 Nitrogen deficiency symptoms – pale-green leaves and pink-reddish petioles.

Plates 2a and 2b Two stages of potassium deficiency symptoms: above – orange-necrotic lamina of the older leaves; below – typical curling and desiccation of the leaf.

Plate 3 Choked-throat sucker, resulting from stunted growth due to potassium deficiency.

Plate 4 A bunch failed to fill and all leaves desiccated due to extreme potassium deficiency.

Plate 5 "Spike leaf" resulting of temporary calcium deficiency.

Plates 6a and 6b Zinc deficiency symptoms on young leaves (left) – anthocyanin pigmentation on the underside of the lamina and on fully mature leaves (right) — alternating chlorotic stripes.

Plate 7 Manganese toxicity symptoms derived from fungicidal sprays (above) or from high concentrations of available Mn in the soil (below).

1

2a

2b

3

5


4


7


6a


6b

den shortages of K can occur if the K release rates of the soil do not match changes in seasonal demand for K by the plant. In these instances the plant may bunch satisfactorily and then the leaf system will suddenly collapse as K is withdrawn from the leaves to supply the needs of the growing fruit (Plate 4) *[102]*.

6.3.1 Uptake of potassium

The expected relationship between K concentration in solution and total plant uptake would follow curve A in Figure 3. If other factors were limiting K uptake, curves B or C may be appropriate. In sand culture experiments, K uptake curves are similar to the expected form, A *[42, 94]* but in

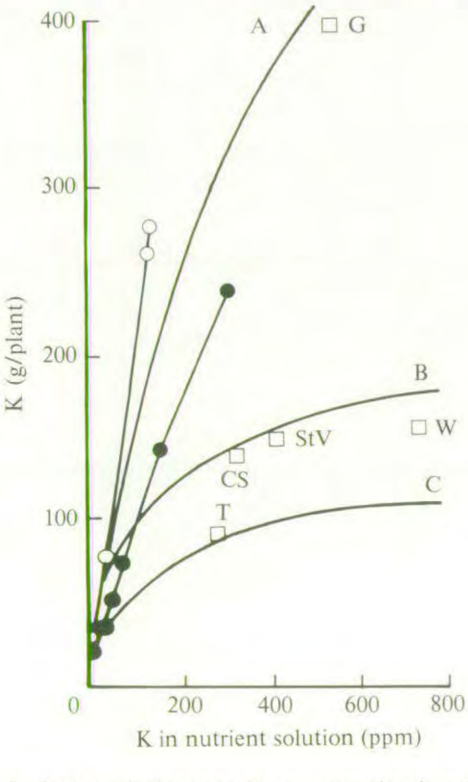


Fig. 3. The expected relationship between K concentration in solution around the roots and total K uptake at fruit maturity. A – normal uptake. B and C – limitations in K uptake. Data from sand culture experiments in Israel (● *[42]*) and Australia (○ *[94]*) and from field studies in the Windward Islands (□ *[106]*). T – Trinidad; CS – Cul de Sac, St. Lucia; W – Winban, St. Lucia; StV – St. Vincent; G – Grenada.

the field, simple relationships between concentration and uptake are more difficult to establish. Field data for five sites in the Windward Islands were incorporated into Figure 3, taking account of soil exchangeable K and fertilizer K. Except for the Grenada site *[G]* all sites have a lower plant K than might be expected from the concentration in the soil solution because of limitations of low Mg *(StV)*, low N *(CS)*, low K *(T)* and high Ca + Mg *(W)* *[106]*.

Studies of the ontogenetic course of K uptake under field conditions have shown an overall decrease in whole plant concentration of K in the dry matter from sucker to fruit harvest *[59]*. That is, K uptake is proportionally greater than dry matter accumulation early in the life of the plant. If K uptake is restricted by low K supply or some other factor the greatest K uptake rate occurs in the first half of the vegetative phase. This K is redistributed within the plant to allow further accumulation of dry matter. Where K supply is abundant large amounts of K are absorbed during the latter half of the vegetative phase as well *[106]*. Even when K supply is abundant, K uptake after bunch emergence is reduced. This variation in K uptake during the life cycle is appropriate to fertilizing the plant crop but it is not relevant to ratoons, since stools have mother plants and followers present at the same time.

Internal plant factors governing the apparent root transfer coefficient *[81]* for potassium were found to be balanced by external effects such that the coefficient was stable over a wide range of K supply. Low K supply reduced specific root weight, relative growth rate and relative concentration change but a threefold increase in concentration ratio compensated for these changes *[101]*.

The regulation of ion uptake by the plant can take place at the root surface and/or at the site of transfer of nutrients to the xylem. Where K supply is low the transfer of N, P, Ca, Mg, Na, Mn, Cu and Zn across the xylem is restricted *[94]*; the exception is K itself, a constant proportion of which is transferred to the top of the plant irrespective of K supply. The relationship of K to other ions will be discussed in section 6.16.

6.3.2 Potassium and growth

Insufficient K supply reduces the total dry matter production of banana plants and the distribution of dry matter within the plant. The organ most drastically affected is the bunch, hence the importance of K in banana growing. *Turner and Barkus [98]* found that while low K supply halved the total dry matter produced, the bunch was reduced by 80 percent and the roots were unaffected. It was suggested that of the various organs competing for K, those nearest the source of supply are the most successful in obtaining their requirements.

Low K supply reduced respiration but produced large variation in the photosynthesis of leaf discs *[60]*. Total dry matter is the balance between gross photosynthesis and respiration. If respiration is lower in K deficient plants then the main effect of low K supply on dry matter production would be through reduction of photosynthesis. While *Martin-Prével* suggested a major effect of K through stomatal control, the importance of K deficiency on mesophyll resistance still needs to be established in the banana plant.

Potassium deficiency impairs protein synthesis since free amino acids *[24]* and soluble forms of N *[60]* increase in low K plants.

Fruit growth is restricted by low K supply in two ways. The translocation of carbon compounds from the leaves to the fruit is reduced and, even when sugars reach the fruit their conversion to starch is restricted *[60]*. Thus low K supply produces "thin" fruit and fragile bunches, a phenomenon frequently observed in the field as well as in experiments.

At a K supply above that which influences growth and yield, changes in reducing, non-reducing and total sugars have been observed. As K supply increased the sugar/acid ratio increased because of increased sugars as well as reduced acidity *[107]*. Thus K supply has an effect on fruit quality over and above its influence on yield.

6.3.3 Potassium fertilizer practice

It is generally accepted that since the banana has a high demand for K and a shallow root system a response to K fertilizer can be expected if exchangeable soil K is less than about 0.4 me/100 g *[111]*. This generalization has been questioned by *Warner and Fox [112]* who found that K fertilizer does not always penetrate the soil and adequate K can be obtained by deep roots. *Lahav [46]* showed that penetration was directly proportional to application rate but 600 kg K/ha/yr was required to obtain penetration to 20 cm.

Twyford and Walmsley [106] highlighted the value of spent pseudostems in cycling nutrients and its implications for fertilizer applications. On poor soils they suggested that a large amount of K be applied to the plant crop (about 2000 kg K/ha) if high yields are to be obtained. In ratoon crops this amount could be reduced by nearly 90 percent (see also section 7).

Potassium chloride is the form of K usually applied to banana plantations. Some advantages can be obtained by using K_2SO_4, especially if bananas are grown together with avocados which are sensitive to chlorine. Potassium nitrate can also be used as a K source for bananas.

6.4 Calcium

Although calcium is a very immobile element in plants, early descriptions of Ca deficiency in bananas referred to a marginal scorch on older leaves *[24, 77]*. It appears that these symptoms may have been an artefact of high Na supply since *Martin-Prével and Charpentier [65]* found the first symptoms on young leaves whose lateral veins thickened, especially near the midrib. About ten days later marginal interveinal chlorosis commenced, frequently near the tip of the leaf. When these patches senesced they expanded towards the midrib, giving the leaf a "sawtooth" appearance.
In the field Ca deficiency symptoms, include "spike leaf" symptoms, *i. e.* leaves on which the lamina is deformed or almost absent *[5, 68]*. These latter symptoms have not been reported in sand culture, even by *Charpentier and Martin-Prével [11]* who alternated the supply of Ca to the plant. The "spike leaf" symptoms (Plate 5) are thought to result from a temporary shortage of Ca within the plant caused by a flush of rapid growth. Evidence for this is circumstantial but in Australia the "spike leaf" symptoms appear in early summer after a spring flush of growth and in plantations receiving high amounts of K. Symptoms also appear some eight weeks after heavy cyclone damage, again associated with a flush of growth. Another cause is thought to be the cold weather of the previous winter *[5]* but this is unlikely since the affected lamina is not present then and does not commence development until mid-spring *[92]*. Affected plants in Australia have about half the concentration of Ca in leaf 3 dry matter as compared with healthy plants growing nearby *[86]*. "Spike leaf" symptoms and thickening of secondary veins are similar to S and B deficiencies in sand culture (see sections 6.6 and 6.11 and Table 6). In Ca-deficient plants fruit quality is inferior and the skin splits when ripe *[10]*.

6.4.1 Uptake of calcium

The uptake of Ca during the course of plant growth follows dry matter accumulation at least until bunch emergence. During fruit growth further uptake of Ca depends upon the site *[106]*. We explored the Cavendish group to determine factors associated with whole plant Ca uptake *[56, 76, 106]*. We defined a soil exchangeable Ca availability index, Δ, as Ca/(K + Ca + Mg), where concentrations are in milliequivalents/100 g soil. The optimum value for Δ was 0.7 (Figure 4) and we extrapolated to nil Ca uptake at $\Delta = 0.4$ and 1.0. Relative Ca uptake (Ca_r) was related to Δ as

$$Ca_r = Ca_{pmax}\ 11.11\ (\Delta - 0.4)\ (1.0 - \Delta)$$

where Ca_{pmax} is the maximum Ca uptake and is influenced by variety and climate.
Calcium is supplied to banana plantations in superphosphate (21% Ca)

and mixed fertilizers containing superphosphate, as well as in the carbonate form as lime or dolomite. The latter are usually applied to adjust soil pH rather than to increase the supply of Ca as a plant nutrient, although the two go hand in hand. The amount of lime applied depends upon the change in soil pH required and the buffering capacity of the soil. A common rate for bananas is three to six t/ha every 3–5 years.

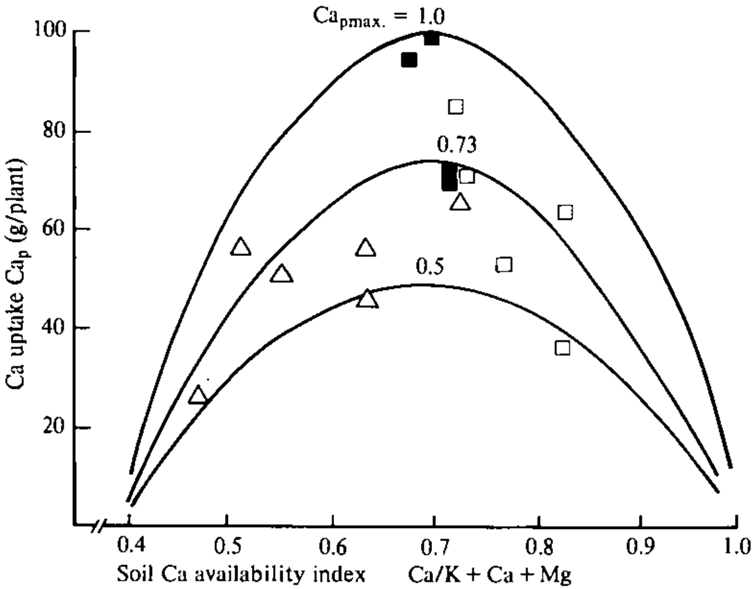


Fig. 4. Whole plant Ca uptake in relation to soil Ca availability index △. Data from field studies in the Antilles (△ *[68]*), Windward Islands (□ *[106]*) and Cameroon (■ *[56]*).

6.5 Magnesium

Magnesium deficiency and excess have been reported from many countries where bananas are grown. Deficiencies usually occur where bananas have been grown for 10–20 years, without Mg fertilizer *[7]* or where high amounts of K fertilizer have been used for a number of years *[71]*. Deficiency symptoms have been described in sand culture *[23, 65, 77]* and in the field *[7, 102]*. A large range of leaf symptoms have been attributed to Mg deficiency including marginal yellowing extending to near the midrib, changes in phyllotaxy, purple mottling of the petioles, marginal necrosis and separation of leaf sheaths from the pseudostem. In sand culture, marginal necrosis is often observed but the most common symptom in the field is that the leaf margins of older leaves usually remain green while the area between the margin and the midrib become chlorotic (Plate 8). Mg toxicity is associated with a condition known as "deforestation blue" (see 6.16).

6.5.1 Magnesium uptake

Using the apparent root transfer coefficient of *Nye and Tinker [82]* it was found that the uptake of Mg by the whole plant was largely influenced by the concentration of Mg in the solution around the roots and much less affected by plant growth *[101]*. These conclusions seem relevant to the whole plant field studies *[68, 76]*, as there was no relationship between whole plant dry weight and whole plant Mg uptake (Figure 5a) but a rectangular hyperbola relationship existed between Mg concentration in the soil and whole plant Mg uptake (Figure 5b curve A). As with K uptake, other factors may limit Mg uptake (Figure 5b curve B).

6.5.2 Magnesium and growth

Without any Mg supply the banana eventually dies *[10]* but the field situation is usually one of restricted supply rather than a total absence of Mg. The relationship between Mg supply, growth and symptom expression appears complex; for example, *Charpentier and Martin-Prével [10]* produced plants in sand culture which had severe deficiency symptoms early in their life but yield was unaffected. *Turner and Barkus [98]* observed a 20% reduction in fruit dry matter on plants grown in sand culture with low Mg supply, but no symptoms appeared on the leaves. The different cultivars and environments of these two studies ('Poyo' in Ivory Coast and 'Williams' in New South Wales, respectively) may account for the different responses. A reduction of yield caused by low Mg supply is proportional to reduced growth in other plant parts, in contrast to the effect of low K supply where bunch size is reduced more than other plant parts *[42, 98]*.

6.5.3 Magnesium fertilizers

Many soils have a reasonable supply of magnesium and deficiency problems occur usually only after many years of banana cultivation. Although symptoms expression is not necessarily associated with reduced yields, Mg is usually applied when symptoms occur. Under these conditions the simple addition of Mg containing compounds to the soil does not always give

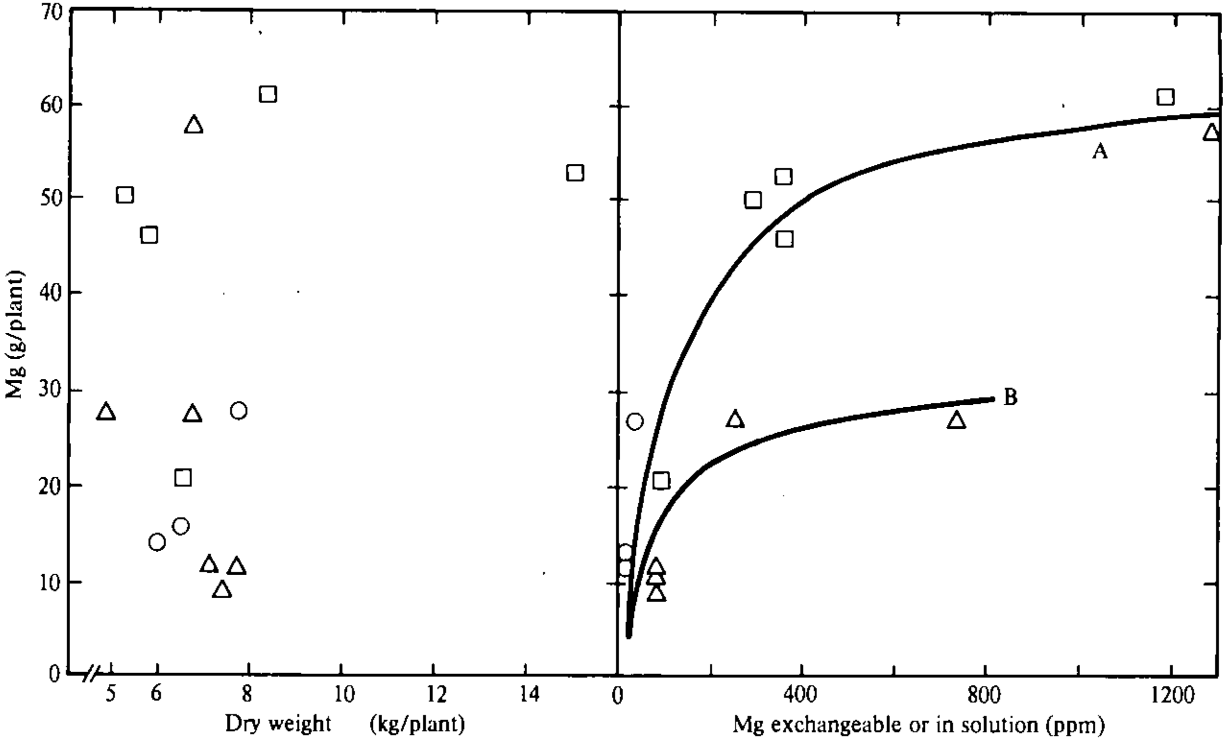


Fig. 5. Whole plant Mg uptake in relation to whole plant dry weight (left) and to exchangeable Mg in the soil or in solution (right). A – normal uptake, B – limitations in Mg uptake. Data from field studies in the Antilles (△ *[68]*), Windward Islands (□ *[106]*) and from sand culture in Australia (○ *[94]*).

the expected rapid response *[102]* and it may be necessary to replant and incorporate the Mg into the root zone to correct the problem.

A sounder approach is to incorporate Mg into N, P, K mixtures so that small regular additions of Mg are given to the bananas *[71]*. Field experience shows that soluble Mg fertilizers (e. g. $MgSO_4$) applied to the soil give a more rapid response than the less soluble compounds, but they are also more expensive. Sprays of $MgSO_4$ applied to the leaves can increase the concentration of Mg in leaf dry matter *[72]*. Since Mg deficiency is unlikely to become a sudden problem in the field, the regular application of small amounts seems advisable. A regular monitoring of Mg concentrations in plant and soil seems a useful way of anticipating low Mg supply.

6.6 Sulphur

Deficiencies of sulphur have been reported in the field as well as in sand culture experiments *[10, 58, 70]*. Symptoms appear in the young leaves, which are yellowish white. As the deficiency progresses, necrotic patches appear on the leaf margins and slight thickening of the veins occurs, similar to B and Ca deficiencies. Sometimes the morphology of the leaf is changed and a bladeless leaf appears, again similar to B and Ca deficiencies, growth is stunted and the bunch is very small or choked.

The most rapid uptake of S occurs from the sucker to shooting stage. After shooting the uptake rate is reduced and S needed for fruit growth comes from the leaves and pseudostem *[110]*. Sulphate concentrations below about 2 ppm and above 10 ppm in solution depress growth and cause an increase in N concentration in the leaves *[22]*, contrary to the effect of S deficiency on N in most other plants.

Most S is applied to bananas as $(NH_4)_2SO_4$, K_2SO_4 or superphosphate. In the Windward Islands 127 kg S/ha is needed to establish the plant crop. Subsequent losses in fruit removal amount to 17 kg/ha/yr *[110]*. NPK fertilizer containing 4% S is used to avoid yield losses caused by S deficiency *[70]*.

In Cameroons *[58]* S was applied at 1 t/ha/yr to soils with high exchangeable basis but only a small non-significant yield increase (about 10%) was recorded in the second and third crops. Regular applications of 50 kg/ha/yr are recommended to avoid deficiencies.

If sulphur-containing fertilizers such as $(NH_4)_2SO_4$, K_2SO_4 and superphosphate are not used, S should be applied separately.

6.7 Manganese

Jordine [38] reported Mn deficiency in bananas in the field in Jamaica and *Charpentier and Martin-Prével [10]* investigated Mn deficiency and excess in sand culture in Ivory Coast. The characteristic features of deficiency are "comb tooth" chlorosis and the presence of the fungus *Deightoniella torulosa* in chlorotic areas. The chlorosis starts marginally on the second or third youngest leaf and sometimes leaves a narrow green edge at the leaf margins, it then spreads along the main veins towards the midrib, interveinal areas remaining green – hence the "comb tooth" appearance *[10]*. While normal-sized bunches are produced by deficient plants (at least in the first generation), the fruit is covered with black spots. Poor fruit development is partly associated with the premature death of the leaves caused by *Deightoniella* infection.

Manganese excess is thought to be a greater problem, world wide, than manganese deficiency, and *Butler [3]* reports experiments in Jamaica where 20 kg Mn/ha/yr reduced yields by 5%. Symptoms appearing on leaves with high concentrations of Mn have been associated with Mn toxicity in Northern Queensland (Plate 7). The high Mn may be derived from fungicidal sprays or from high concentrations of available Mn in the soil. However, in sand culture experiments high Mn has failed to reduce yield *[10, 98]*.

In sand culture *Turner [94]* found that Mn at ten times the standard concentration reduced whole plant uptake of Ca, Mg and Zn by 28, 39 and 23% respectively while whole plant uptake of Mn increased sevenfold. The tolerance of banana to high concentrations of Mn in the soil solution is high but they also show that high Mn could be a problem in acid soils with marginal amounts of available Ca, Mg and Zn. The Mn toxicity observed in the field could therefore be attributed to the indirect effects of other elements rather than to a high concentration of Mn. The correction of Mn deficiency can be achieved by sprays or ground application of $MnSO_4$ *[38]*. A tentative annual rate of 7 to 11 kg/ha of Mn is suggested *[57, 105]*. The yield depression observed by *Butler [3]* at 20 kg/ha of Mn is not consistent with the tolerance of the banana to high concentrations of Mn in the sand culture experiments mentioned previously. Silicon may be an ameliorating factor here. High Mn in the field can be avoided by liming.

6.8 Zinc

The most widely reported minor element deficiency of bananas is zinc *[6, 38, 74]*. It has often been confused with virus infection *[23]*. Zinc deficiency occurs more usually on naturally high pH soils or on highly limed soils. Calcareous soils are particularly prone to Zn deficiency as Zn ions in the chelate complex can be replaced by Ca ions. Also in organic and peat soils Zn availability may be restricted.

The characteristic symptoms appear in the young leaves which become significantly smaller in size and more lanceolate in shape *[38]*. The emerging leaf has a high amount of anthocyanin pigmentation on its underside (Plate 6a), which often disappears as the leaf unfurls. The unfurled leaf has alternating chlorotic and green bands (Plate 6b). The fruit is sometimes twisted with a light green colour. Similar symptoms are described in Colombia as "rayadilla" *[6]*.

Zn deficiency symptoms may appear without any apparent reduction in growth or yield but if the deficiency persists, plants of the next cycle are stunted *[10]*. Sometimes Zn deficiency may result from high P concentration as consequence of P/Zn antagonism *(cf.* Figure 6) *[53, 57]*.

Since Zn is leached under acid conditions and fixed under alkaline conditions it is easy to correct its deficiency with a spray of 0.5% $ZnSO_4$ *[38]*.

The Zn requirement of the banana is relatively small. On the basis of whole plant analysis *Twyford and Walmsley [105]* suggested a rate of about 1.0 kg/ha/yr of Zn. Field experiments in Australia on acid soils showed that 2 to 3 times this amount was required to correct the deficiency *(C. Eady*, personal communication). Zn chelates are also sometimes used. Zn applications are not given regularly but rather the problem is corrected as it occurs.

6.9 Iron

Deficiency of iron in bananas has been reported in the field in Hawaii *[12]* and Israel *[113]* where it is associated with calcareous soils. The most common symptom, which occurs on young leaves, is the chlorosis of the entire leaf. Leaves may become yellow-white (Plate 9a). The chlorosis is more acute in the spring and autumn than in the summer and is more evident under dry conditions *[113]*.

The total amount of Fe absorbed by a healthy plant is only about 1 g and 80% of this amount is absorbed during the first half of the plant's life *[110]*.

Fe deficiency can be corrected with foliar sprays of 0.5% $FeSO_4$ or iron chelate (Fe-EDTA). The chelate form can be applied directly to the soil, by spraying on the leaves or through the irrigation water (1 ppm).

A black, necrotic marginal scorch on older leaves (Plate 9b) has been associated with high leaf Fe concentrations in the Canary Islands *[1]*.

6.10 Copper

Copper is needed by banana plants in very small amounts. Total Cu uptake is about 1% of Mn uptake *[110]*. Cu is actively absorbed and it can be translocated within the plant when supply is adequate *[69]*. Cu deficiencies have been described in pot culture *[10]* and in Ivory Coast in the field *[75]*.

Deficiency symptoms appear on all leaves. They are similar to those of N deficiency in that a general uniform paleness of the leaf laminae occurs. The petioles are not pink but the midrib bends giving the plant an umbrella-like appearance. Deficient plants are sensitive to fungal and virus attack *[75]*.

As with Zn it is preferable to correct Cu deficiency with a leaf spray of 0.5% neutralized $CuSO_4$ than to apply it to the soil. *Twyford and Walmsley [106]* suggest 1 kg/ha of $CuSO_4$ as an annual rate applied to the soil. In India, application of 4 ppm Cu to plants in sand culture increased the growth of suckers. Copper oxide and copper chelates can also be applied.

If copper is regularly sprayed on bananas as Bordeaux mixture for Sigatoka *(Mycosphaerella musicola)* control, after 15–20 years Cu can accumulate in the soil and inhibit root growth. Deep ploughing and liming can overcome the problem *[87]*.

6.11 Boron

Boron deficiency symptoms have been recorded in the field in Ecuador *[90]* and in sand culture *[10, 11, 80]*. Symptoms include reduced leaf area, curling and lamina deformation and most characteristically, stripes perpendicular to the veins on the underneath of the lamina (Plate 10a). The new leaves may have an incomplete lamina, similar to S and Ca deficiencies. Thickening of secondary veins has also been reported. Marginal paling and necrosis is reported as B excess symptoms (Plate 10b).

The rate of B uptake in field-grown plants is constant throughout the life cycle, from sucker to harvest, being about 40 mg/plant/month *[110]*. Boron taken up after bunch emergence is used for fruit growth. *Coke and Boland [11]* studied the effect of 0–10 ppm B in solution on the growth of 'Valery' bananas and tentatively recommended that soil concentrations should be in the range of 0.1 to 1.0 ppm B.

About 12 kg/ha of borax has been suggested as an amount which should overcome deficiencies *[105]*.

Plate 8 Magnesium deficiency symptoms – chlorosis of the lamina with the margins remain green.

Plates 9a and 9b Iron deficiency symptoms on calcareous soil (above) – yellow-white complete chlorosis, and iron excess symptoms (below) – black margins.

Plates 10a and 10b Boron deficiency symptoms (above) – stripes perpendicular to the veins. Less than 2 ppm B in lamina. B excess symptoms (below) – marginal paling with necrosis, more than 850 ppm B in lamina.

Plate 11 Marginal chlorosis and necrosis resulting from excess of sodium.

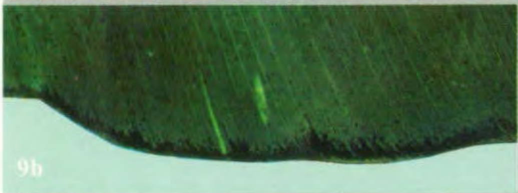
Plate 12 Disintegration of the pseudostem after very rapid growth resulting from excessive manuring.


8


10a


9a


10b


9b


11


12

6.12 Molybdenum

Symptoms of Mo deficiency in banana have not been recorded in sand culture or in the field. *Srivastava [85]* in India increased the root growth and development of banana plants in sand culture with sprays containing Mo at 4 ppm but no deficiency symptoms were recorded.

6.13 Sodium and chlorine

The banana plant has a relatively moderate resistance to salinity but salt problems occur in Haiti, Dominican Republic, Ecuador, Colombia, Jamaica, Israel and the Canary Islands. *Dunlap and McGregor [17]* found that when the soil has 100–500 ppm total soluble salts banana growth is satisfactory, from 500–1000 ppm plants and fruit are visibly affected and above 1000 ppm plants are stunted or dead. Saline soils produce marginal chlorosis leading to necrosis, stunted growth and thin, deformed fruit. Leaching with good quality water can reduce salting problems.

Veerannah et al. [108] screened 70 banana varieties for salt tolerance. In solutions up to 0.25 M NaCl, midrib tissues were unaffected, above this concentration the response varied but there was as much variation within genomic groups as between them. The toxic limit was 0.75 M except for three AAB and three ABB varieties.

Bananas are thought to be more sensitive to Na than Cl. In some parts of Israel bananas are irrigated with water containing 500–600 ppm Cl, but this seems to be the upper limit for salinity for commercial banana growing. Where Cl toxicity is suspected sucker growth is reduced and fruit will not fill. In these cases fertilizers containing Cl are avoided and the high K requirement of the plant is satisfied using K_2SO_4 or KNO_3.

Sodium toxicity is described as a marginal chlorosis around the lower leaves (Plate 11). These areas became necrotic until about one third of the leaf is affected. Same symptoms were observed in Ecuador. Under saline conditions the concentration of Na in the roots is three times the normal concentration of 0.5% *[37]*. The concentration of Na in the conducting tissues can rise to 1.0 percent if K is very deficient *[48]*.

Sodium interfered with K uptake by bananas in the Canary Islands, but the soil K/Na ratio used by *Garcia et al. [26]* accounts for only 22% of the variation in pseudostem circumference. We re-examined their data and 60% of the variation in pseudostem circumference (Φ) can be accounted for with soil organic matter (O_m) and the ratio K/(Ca + Mg + Na + K) *i. e.*

$$\Phi = 73.85 + 0.121\ O_m + 1.139\ K/(Ca + Mg + Na + K)$$
$$r^2 = 0.60$$

Since Na and Mg are added to the soil in the irrigation water, K can become less available even though the Canary Islands soils are rich in potassium *[20]*.

6.14 Arsenic

Arsenic toxicity has been reported by *Fergus [19]* in Australia. Leaves of all ages have chlorotic stripes and bunch development is poor. Affected plants had 0.25–2 ppm As in the leaf dry matter and healthy plants had 0–0.5 ppm.
The condition can be cured by spreading around the plant 50–100 kg of soil *(e. g.* krasnozem) which will adsorb As and render it unavailable to the plants.

6.15 Aluminium

Since aluminium is not an essential element for growth, our concern is with possible toxic effects, especially when the soil pH is below 4.0 *[31]*. Whole plant Al uptake at two sites in the Windward Islands was found to be only 0.9 and 1.5 g Al per plant. The soil pH was 5.4 and 6.1 respectively *[110]*. If Al is toxic to bananas the symptoms have yet to be described.

6.16 Interactions between nutrients

When the increasing supply of one ion results in a lowering of concentrations of other ions an antagonism is said to take place. The reverse is called synergism. In other plants the physiological basis for these observations remains unclear and in short-term experiments ion antagonism is not often observed *[69]*. The significance of interactions and their contribution to the understanding of banana plant nutrition needs to be questioned.
In bananas nutrient antagonisms have been studied in depth by several research workers *[41, 48, 53, 67]*. The main cations examined have been K, Ca and Mg, although many antagonisms and synergisms have been reported (Table 9). Some field problems have been associated with nutrient antagonisms. Finger drop or 'dégrain', a post harvest problem of ripe banana bunches, has been associated with an N imbalance *[68]*. Dégrain occurs during the hot, wet season in the tropics and, with low K supply, ammonium N accumulates. The excess N delays bunch emergence and produces bunches with widely spaced hands which are easily damaged in transport. The fruit pedicels are fragile and when ripe, fruit fall from the bunch.

Table 9. Effect of mineral deficiencies on the concentration of other nutrients in banana leaves *[41, 48, 57, 68, 78, 94]*.

	Deficient element							
	N	P	K	Ca	Mg	Mn	Zn	S
N	–		–		+0			+0
P	+	–	–	+	–	0	+	+
K	+		–	+	+0	0	–	
Ca	–		+	–	+0	±		+
Mg	+	–	+	+	–	+		0
Mn			–		+	–		
Cu			+		0			
Zn			0		0		0	
Fe		–						
Na		–	0					
Cl			+					

+ increase; – decrease; ± both changes observed; 0 no effect.

Mottling of the petiole, called "blue", has been associated with a low K/Mg ratio in the field *[68]*. However, in a sand culture study *Charpentier and Martin-Prével [10]* investigated K:Ca:Mg imbalance and found that "blue" was caused by K deficiency and was not related to high Mg supply. In the same sand culture experiment a high K/Mg ratio caused a "yellow pulp" condition in the ripe fruit, while yield was unaffected. High soil Ca and Mn deficiency have also been associated with yellow pulp *[10]*.

Changes in the K/Ca + Mg, P/Zn and N/P ratios were associated with changes in yield in an experiment with KNO_3 and manure in Israel (Figure 6) *[53]*. Whether causal relationships exist between these ratios and yields needs to be established, since each could have been independently influenced by the treatment.

The magnitude of an antagonism depends very much on the organ in which concentration changes are measured *[67]*. For example, increasing K supply has a large depressing effect on Mg concentrations in leaves and pseudostem but very little effect in fruit and roots (Table 10).

The observed K/Mg antagonism in bananas could be a consequence of K and Mg operating independently of one another or of these two factors

- increased K supply promoting the translocation of Mg towards fruits and storage tissues *[69]*
- the addition of K (at constant Mg supply) promoting growth and decreasing whole plant Mg concentration *[94]*.

Martin-Prével and Montagut [68, 76] discuss K:Ca:Mg interactions in the different organs of the banana and their data draw attention to the danger of extrapolating from results in one organ to the behaviour of the plant as a whole. While the data of *Montagut, Martin-Prével and Lacoeuilhe [76]* show a negative association between whole plant K and Mg uptake, the data of *Twyford and Walmsley [106]* (for the same cultivar), and of *Turner [94]* show no association between K and Mg uptake on a whole plant basis but the data of *Lahav [42]* show a curvilinear association (Figure 7). These differences may be caused by different experimental or environmental conditions as well as the presence of other ions. These effects need to be explored further.

The older plant nutrition literature often mentions a synergistic relationship between Mg and P. It was thought that Mg may act as a 'phosphatic carrier', but this seems unlikely *[69]* and *Martin-Prével [63]* discounts this mechanism for bananas (see 6.2).

Future work should explore relationships between nutrient uptake and growth which may account for observed nutrient antagonisms.

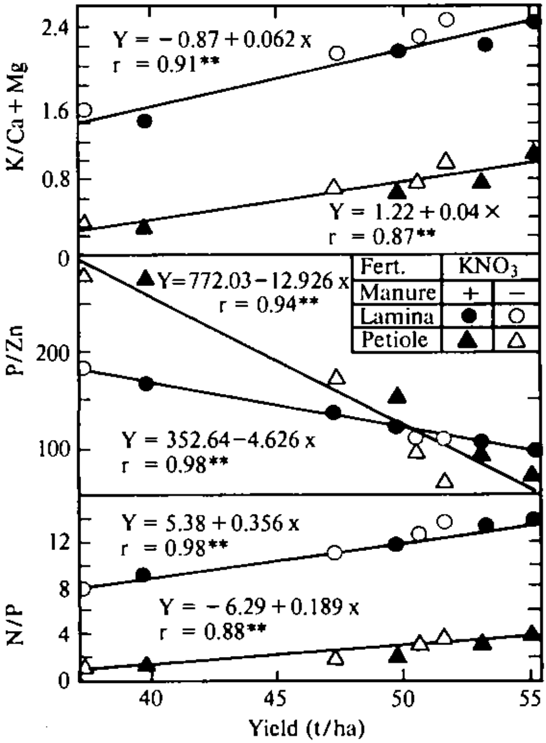
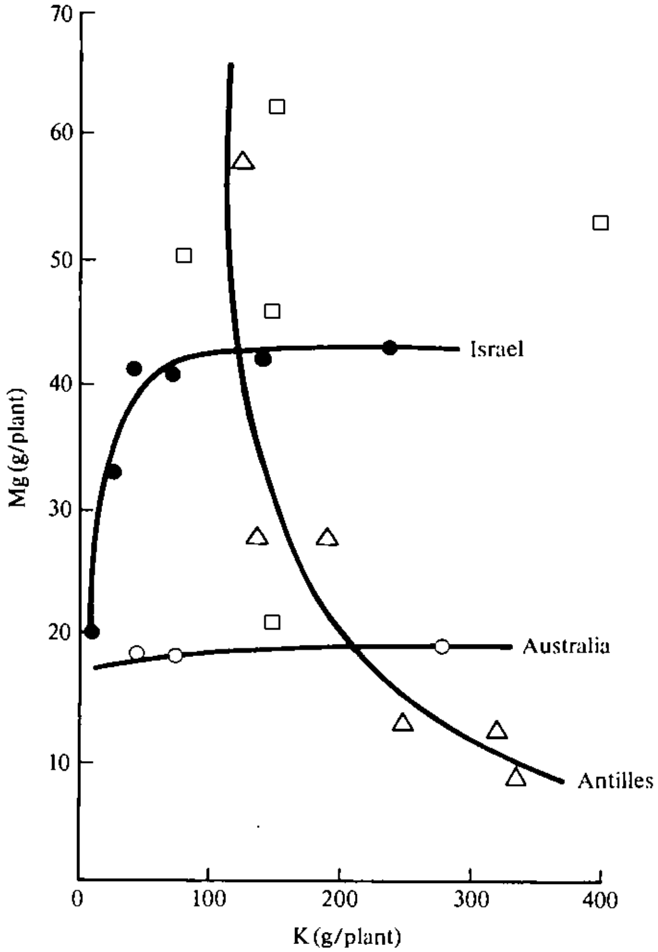


Fig. 6. The relationship between banana yield and K/Ca+Mg, N/P and P/Zn ratio *[53]*.



Cultivar	Experimental Site	Ref.	Symbol
Poyo	Antilles-Field	68	△
Robusta	Windward Is.-Field	106	□
Williams	Australia-Sand culture	94	○
Dwarf	Israel-Sand culture	42	●

Fig. 7. Total plant uptake of K and Mg in four experiments.

Table 10. The effect of K supply in sand culture on Mg concentrations in different plant parts *[94]*.

Mg concentration in	K treatment (mg/l) 12	24	120	LSD (0.05)
Roots	0.32	0.28	0.28	0.07
Corm	0.38	0.40	0.22	0.08
Pseudostem	0.70	0.39	0.28	0.07
Lamina leaf 3	0.45	0.41	0.31	0.02
Bunch stalk	0.23	0.13	0.10	0.03
Fruit	0.22	0.18	0.18	0.03

6.17 Organic manure

Organic manure is used extensively in banana growing in Israel and the Canary Islands, sometimes as much as 500 t/ha/yr being applied. Considerable quantities of N, K and especially P are supplied in the manure.

In a series of experiments with farmyard manure (FYM) in Israel *Lahav [47]* found that FYM up to 80 t/ha/yr enhanced growth, hastened flowering and shortened the flowering to harvest period. FYM alone increased yield by 33%, but it was always beneficial to apply fertilizers with the organic manure. In one experiment 45 t/ha/yr of FYM produced small, statistically non-significant increases in yield in the presence of increasing amounts of KNO_3 (Table 11) *[53]*.

In other experiments, amounts of organic manure (up to 200 t/ha) were found beneficial and chicken manure – which is richer in nutrients, especially P – was superior to FYM and town refuse compost. When heavy manuring is being applied in deficient conditions, too rapid growth may occur, resulting in disintegration of the pseudostem (Plate 12). Most banana growing areas in the world are far removed from sources of organic manure.

Table 11. Effects of KNO_3 with or without FYM on bunch weights, number of bunches/ha and the total yield (5 years average) in Israel *[53]*.

KNO_3 (t/ha/yr)	Bunch weight (kg)		Number of bunches/ha		Yield (t/ha/yr)	
	without manure	with manure	without manure	with manure	without manure	with manure
0	23.3 b *	23.9 b	1650 c	1720 c	37.2 d	39.7 d
0.5	26.2 a	26.0 a	1910 b	2060 ab	47.2 c	49.7 bc
1.0	27.2 a	26.3 a	2000 ab	2110 a	50.5 abc	53.0 ab
2.0	26.4 a	27.4 a	2140 a	2150 a	51.5 abc	55.1 a
S. E.	0.57		62		1.48	

* Means not followed by a letter in common differ significantly

7. Nutrient cycling and its implications

The nutrients within a banana plantation may be regarded as being located in a number of pools (Figure 8). Significant features are the total amount of nutrients present in each pool and the release rate and available reserve in the soil. The proportional distribution of a nutrient between pools depends, to some extent, on the total amount present; for example, where Mg supply is low, a greater proportion of Mg is found in the fruit *[76, 94, 106]*.

7.1 Nutrient losses and gains

Losses from the system include fruit removal, which is easily estimated since of all plant parts the concentration of nutrients in fruit dry matter is the least affected by nutrient supply. It is therefore possible to estimate losses based on the quantity of fruit removed. In Table 12 we summarised data from numerous investigators. However, these data do not contain information on roots and hence the share of removal by the fruit is overestimated. For many elements 32–56% of the total content is removed by the fruit. This is especially emphasized by the large proportions of P and K removed and justifies the large amounts of K applied to bananas. Several minerals (Cl, Na, Mn, Fe, Zn, Al) are removed by the fruit in rela-

Table 12. Average amount of nutrients (kg/ha) in a Cavendish banana plantation. Based on 2000 mother plants/ha with followers and an average bunch weight of 25 kg (roots not included).

Element	Amount removed in 50 t of fresh fruit	Amount in remaining plants	Total	Proportion removed in fruit (%)
N	189	199	388	49
P	29	23	52	56
K	778	660	1438	54
Ca	101	126	227	45
Mg	49	76	125	39
S	23	50	73	32
Cl	75	450	525	14
Na	1.6	9	10.6	15
Mn	0.5	12	12.5	4
Fe	0.9	5	5.9	15
Zn	0.5	4.2	4.7	12
B	0.7	0.57	1.27	55
Cu	0.2	0.17	0.37	54
Al	0.2	2.0	2.2	9
Mo		0.0013		

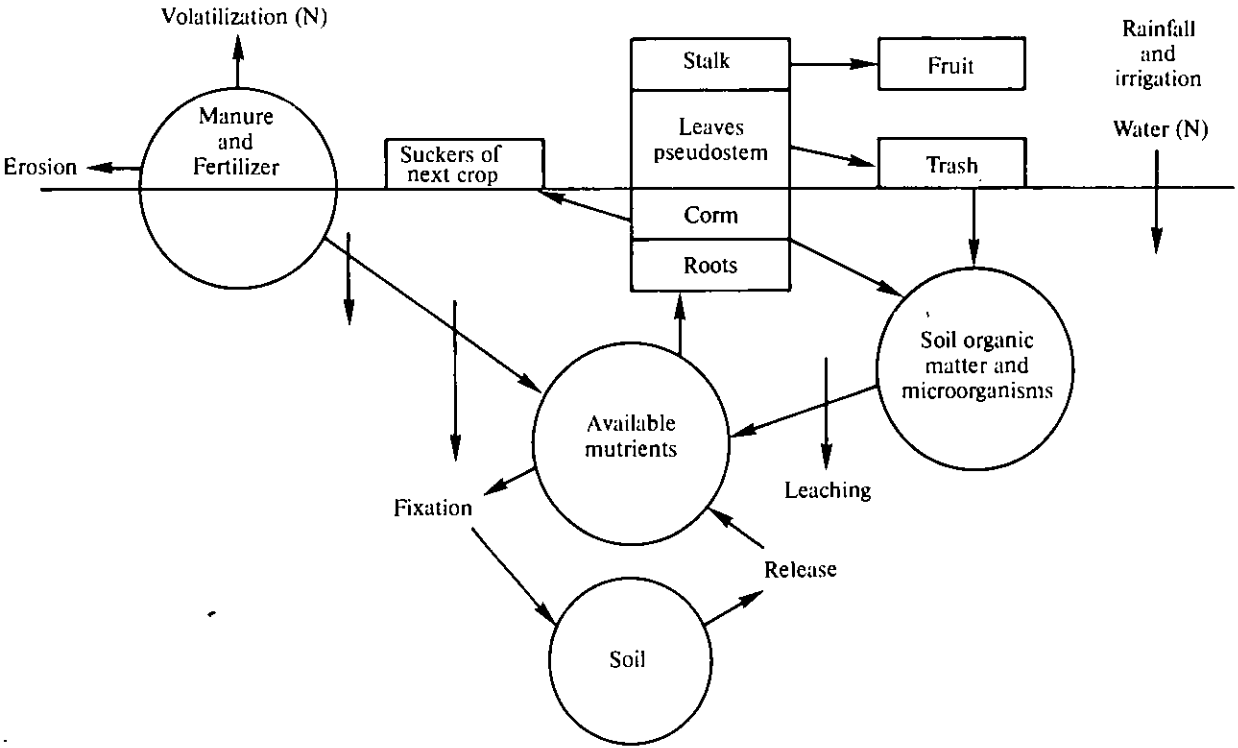


Fig. 8. Schematic representation of the nutrient cycle in bananas. Some nutrients may pass from one crop to another without returning to the soil while the remainder returns through trash and microbial breakdown to the pool of available nutrients in the soil *[29, 30, 95]*.

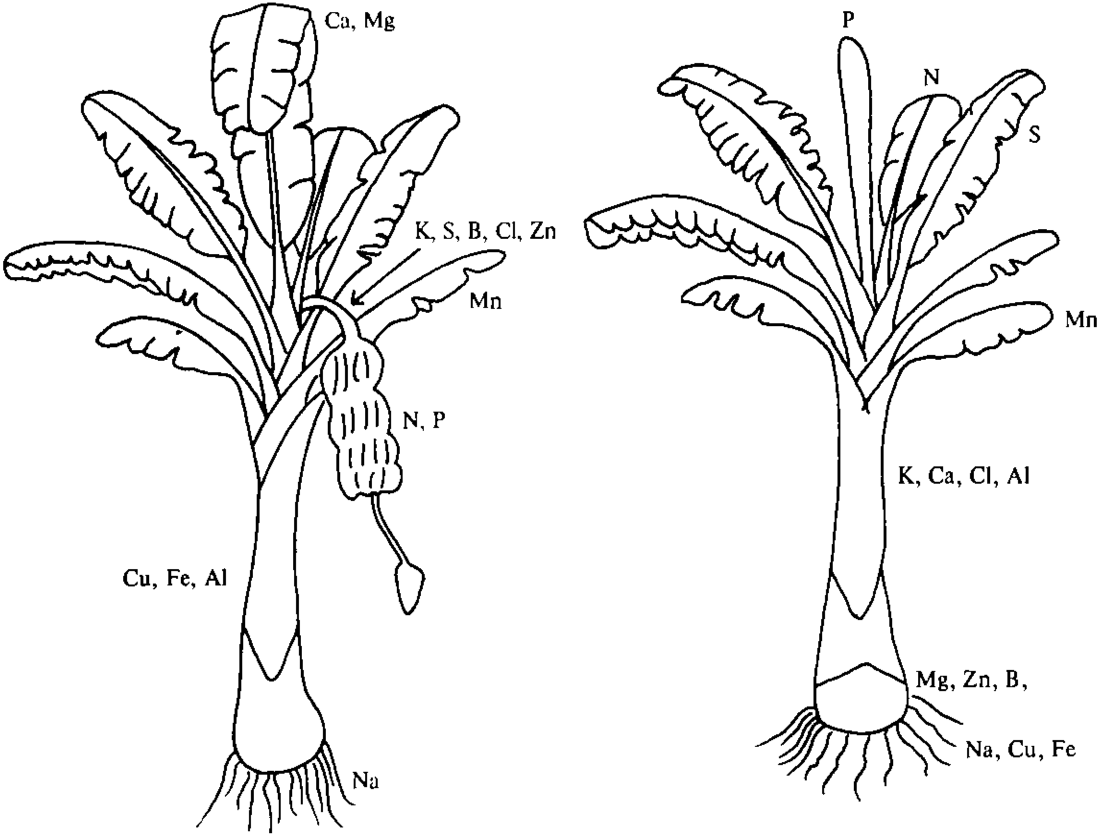


Fig. 9. Highest concentrations of nutrients in various organs in vegetative and fruiting phases of the banana plant.

tively small amounts (4–15% of their total amount). These nutrients are mostly concentrated in the leaves, conductive tissues or roots (Figure 9). Losses caused by leaching and runoff are more difficult to assess but it was shown that under some conditions the losses can be considerable *[30]*. On a low fertility soil with low cation exchange capacity (5–10 me/100 g) and high rainfall (1400–2000 mm/yr) the following losses were recorded in a banana plantation, over a period of 8 years (kg/ha/yr): 165 N, 2.2 P, 376 K, 89 Mg and 360 Ca. These losses represented 60–85% of the elements applied as fertilizer nutrients (except for P). Runoff was relatively unimportant, representing less than 10% of the losses, except for P where 30–50% of the P was lost in runoff. The bulk of the losses occurred during the rainy season. Factors contributing to the high nutrient losses were the poor health of the root system, excessive deep drainage, low exchange capacity of the soil and heavy fertilization. An active root system will absorb nutrients rapidly and allow almost no deep drainage losses *[98]*. The main lesson is that on soils of low fertility, fertilizer application should match the needs of the crop as closely as possible. Application of large amounts of nutrients will lead to excessive loss in deep drainage and possible contamination of ground water supplies.

Estimates of gaseous losses of N and nutrient losses caused by erosion have not been made in banana plantations. In high density plantings erosion is a problem only on steep hillsides during the first year, before the ground is protected by trash.

Nutrient gains can come from rainfall (kg/ha/yr): 42 N, trace P, 2 K, 50 Ca and 40 Mg in Ivory Coast *[30]* and irrigation water. The amount supplied by the latter depends on the source of the water and the quantity applied. In intensively cultivated areas, the content of N in the water might be high. The two major sources of nutrients are the soil and added mineral or organic fertilizers. Soils vary in their ability to supply the nutrient demands of the plant. In the case of K the demand in the subtropics is seasonal and on these soils K deficiency occurs only at the end of the growing season *[102]*. Other soils, such as some in Honduras *[3]*, or those in the Canary Islands have abundant supplies of K and even many years of banana growing fail to reduce soil K *[20]*. However, application to Canary Island soils of Na and Mg in the irrigation water can restrict the supply of K to the plant and responses to K fertilizer can be achieved.

7.2 Movement of nutrients within the system

The banana plant grows in such a way that there are always plants of different sizes present on the one stool at the same time and the parent/sucker relationship is thought to be important in the nutrition of the crop. *Walmsley and Twyford [109]* showed qualitatively that ^{32}P can move readily from one plant on the stool to another over a wide range of plant development. Quantitative losses of nutrients from pseudostems after bunch harvest were estimated as 40% of the young suckers nutrient needs of N, P, K, Ca, Mn and Cu over a ten week period *[95]*. This represents a significant contribution of nutrients to the young growing plant. The practical implications of these data in terms of early desuckering, cutting up pseudostems after harvest and fertilizer placement have been pointed out by *Walmsley and Twyford [109]*.

Movement of nutrients from plants of one generation to the next is a significant feature of nutrient cycling but much less is known about the fate of nutrients in the trash on the ground. The trash consists of leaves and pseudostem left after harvest of the bunch. 150–200 t/ha/yr of fresh material can be added to the soil of banana plantations *[29]*. The total amount of dry matter added in trash is directly proportional to the yield of fresh fruit – 1 t/ha of fresh fruit being equivalent to 1 t/ha of dry material *[106]*. In a high yielding plantation (50 t/ha/yr) in Australia about 10 t of dry matter will be present at any one time *[94]*. Release of nutrients from this material will depend on its rate of breakdown as well as the solubility of the nutrients themselves. Most of the K but very little of the N, Ca and Mg are water soluble, so that the rate of movement of nutrients from the trash to the soil will be a feature of the nutrient itself as well as other factors *[30]*. The rate of transfer of K could be quite high as under Ivory Coast conditions, where breakdown of banana vegetative material, when mixed with the soil, is rapid. Field incubation of banana trash, mixed at 4% with soil, showed that only 10% remained after 4 months *[29]*. Breakdown of trash in the field will be a function of soil temperature and water content. In the subtropics and in the drier growing areas breakdown of trash is slow, the trash completely covering the ground for most of the year.

When nutrients in the trash have been released they may be adsorbed on to the soil before they are re-absorbed by banana roots.

7.3 Implications of nutrient cycling

Knowledge of the size of the various nutrient pools and the rate of movement between them has practical implications for fertilizer practice. *Twyford and Walmsley [106]* have drawn attention to the differences between plant and ratoon crops, the fertilizer needs of the latter being only 15% of those of the former.

The amount of nutrients in the pools is proportional to crop yield in that high yielding crops have large reserves of nutrients in corms, pseudostems, etc. but low yielding crops have much lower reserves. These features are important for frequency of fertilizer application. Frequent applications of fertilizer will be much less important where soil and plant reserves are high, although there may be difficulty in assessing soil reserves, especially of nitrogen *[111]*. Since N does not accumulate in the plant, frequent applications of this element are always preferable *[39]*. Response to added fertilizer may be rapid or slow, depending on the plant and soil reserves. If reserves are low, the amount of nutrient added will be large in relation to the total amount of nutrient present in the soil/plant system and response to added fertilizer may be rapid. Slow or nil responses are to be expected if nutrient reserves are high.

For greatest efficiency of fertilizer use the amount supplied needs to match the maximum productivity of the site. For example, an irrigated plantation yielding 50 t/ha/yr will need twice as much fertilizer to replace fruit removal losses as a non-irrigated one (in the same environment) producing 25 t/ha/yr. In the latter case the yield limiting factor is water supply rather than nutrient supply. The application of high amounts of fertilizer to the non-irrigated site will result in greater nutrient losses through deep drainage *[30]*.

8. Plant analysis

Information on the concentration of nutrients in plant tissues is useful in diagnosing nutrient deficiencies provided standard values are known. Such data can help to distinguish between nutrient deficiencies when symptoms are similar (e. g. N and Cu in bananas) or where multiple deficiencies occur *[102]*. Plant analysis can provide a diagnosis of toxicity as well as deficiency. Soil analysis can also be helpful since it gives a measure of the nutrients available in the soil, but plant analysis can tell us whether these nutrients are being absorbed.

8.1. Factors influencing nutrient concentrations in tissues

To diagnose nutrient deficiencies and excesses using plant analysis is appealing, but it can be used only with reservations, because many factors influence the concentration of nutrients in an organ, apart from nutrient supply.

8.1.1 Organ

The concentration of any nutrient varies from organ to organ within the plant. For example, at the large stage, N concentration is about 3.5% in the dry matter of unemerged leaf tissue but in the corm it may be only 0.5%. *Twyford and Walmsley [106]* found that while the actual concentration of nutrients varied from site to site, the pattern of nutrient concentrations from organ to organ within a plant was similar at all sites in the Windward Islands, and these were not greatly different from those in the French Antilles *[76]*. Organs with high concentrations of each nutrient are shown in Figure 9.

Nutrient concentration can vary considerably within an organ, and this is especially true for the leaf tissue, the organ most commonly used for diagnostic sampling. K, P, Fe and Ca are more concentrated near the leaf base while N, Mg and Mn are more concentrated near the tip *[45, 54, 104]*. The relative change in K from base to tip is about 85%. Variations also occur across the lamina from midrib to margin *[62]*. The magnitude and direction of the gradient for any one element is influenced by the age of the leaf as well as nutrient supply *[41]*.

8.1.2 Ontogeny

As an organ ages the nutrient concentration may increase or decrease. Within the leaf system two factors operate – the physiological age of the leaf (represented by the position of the leaf in relation to the most recently emerged leaf) and the chronological age of the leaf (more important in subtropical climates). In New South Wales and Israel, for example, the third youngest leaf may be only 20 days old in summer or up to 100 days old in early spring *[91]*. Changes of nutrient concentrations with leaf position have been explored many times *[36, 42, 78, 96, 104]*. In healthy plants the concentrations of N, P, K, Cu and Na decrease as the leaf ages, the concentrations of Ca, Fe, Mn, Zn and Mg increase and S, B and Cl are reasonably stable (Figure 10) *[22, 42, 96]*. *Murray [78]* showed that nutrient supply influenced the rate of change of concentration from one lamina to the next. For example, in his work K concentration was relatively constant from the youngest to the oldest leaf, when K supply was adequate, but it decreased sharply with leaf age when K was deficient.

Changes in nutrient composition associated with the ontogeny of the plant can occur. Nutrients in lamina 3 which decrease with increasing plant size are P, Mn, Cu and Zn while N, K and Mg show higher concentrations in medium-large suckers *[96]*. After bunch emergence mobile nutrients can be redistributed within the plant and nutrients can move from the leaf system to the growing fruit. A decrease in nutrient concentrations in the lamina is often observed between bunch emergence and harvest *[41, 45, 62, 106]*. The magnitude of the change depends upon the nutrient concerned, the external nutrient supply *[41]*, and climatic changes from bunch emergence to harvest. The concentration of a nutrient in an organ is the ratio between the amount of nutrient accumulated and the amount of dry matter accumulated. If dry matter increases but no change in the amount of nutrient occurs the concentration decreases. This change, dilution associated with growth, is frequently observed during organ ontogeny. When the effects of plant ontogeny are being assessed, seasonal influences need to be accounted for, especially if the same plant is sampled at different times *[54]*.

8.1.3 Variety

Differences between varieties are difficult to assess from the literature since a range of varieties has not been grown in the one climate with differential nutrient supply. What little data are available suggests that varietal differences are important, especially in relation to critical concentrations *[41, 62]*, although these differences have sometimes been ignored *[96]*. Recently *Turner and Barkus [100]* compared the nutrient concentrations in lamina 3 of 30 banana varieties. They found that varieties with a *balbisiana* constitution had lower concentrations of N, P, S, K, Mn, Cu and Zn than other wild species or *acuminata* based varieties. For plants with AAA constitution, the Red group had lower concentrations of N, P,

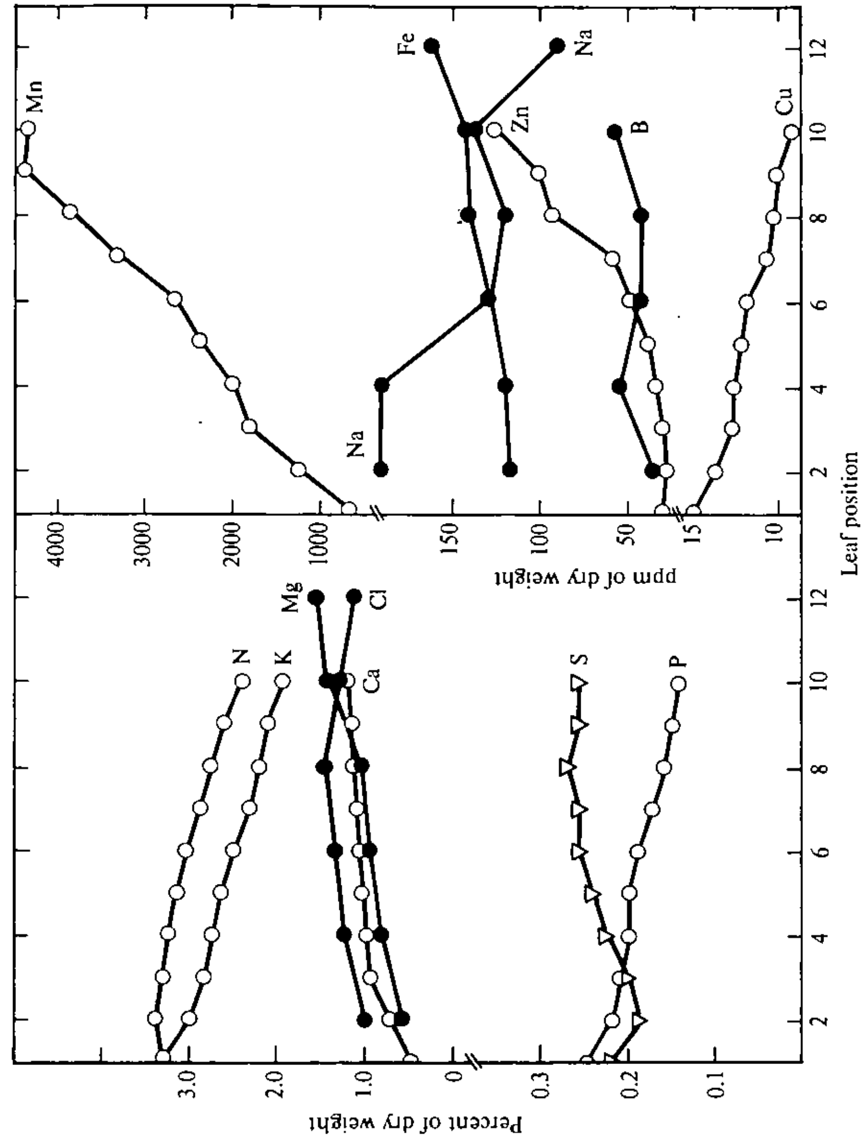


Fig. 10. Nutrient concentration in lamina dry matter at various leaf positions. Data from *Turner and Barkus* (○ *[96]*), *Fox et al* (△ *[22]*) and *Lahav* (● *[42, 48]*).

S, Mg, Fe, Mn and Cu than the Cavendish group. Within the Cavendish group trends were less obvious, effects being associated with extremes of plant height. Among the Cavendish varieties of commercial importance variation was least for N, K and Cu but greatest for Mo, Al and Mn (Table 13).

Table 13. Mean and coefficient of variation of nutrient concentrations in lamina 3 of 13 Cavendish varieties grown in Australia *[100]*.

Element	Units	Mean	Coefficient of variations (percent)
N	percent	3.69	2.3
P	percent	0.21	3.6
S	percent	0.28	3.9
K	percent	3.27	2.5
Ca	percent	0.79	20.3
Mg	percent	0.36	4.7
Cl	percent	0.76	6.4
Al	ppm	41.3	26.8
Fe	ppm	150	12.5
Mn	ppm	1476	23.7
Cu	ppm	12.1	2.3
Zn	ppm	17.6	16.5
B	ppm	16.8	5.9
Mo	ppm	0.155	41.0

8.1.4 Season

Season influences the concentration of nutrients in the tissues of other plants and the banana is no exception, especially in the subtropics *[96]*. The concentration of N is usually high in the spring and lowest in the autumn-winter period, but the concentrations of other elements such as K and Mg is much less predictable (Figure 11). These influences can have an important bearing on the interpretation of banana leaf analyses. The relationship between nutrient concentration in the lamina and that in the solution around the roots, follows a rectangular hyperbolae, the maximum value of which was influenced by season (Figure 12) *[99]*.
Whether similar relationships exist in the tropics needs to be established but seasonal influences can be considerable *[66]*.

8.1.5 Nutrient concentration around the roots

Precise relationships between nutrient concentrations around the roots and nutrient concentrations in the leaves remain elusive because it is diffi-

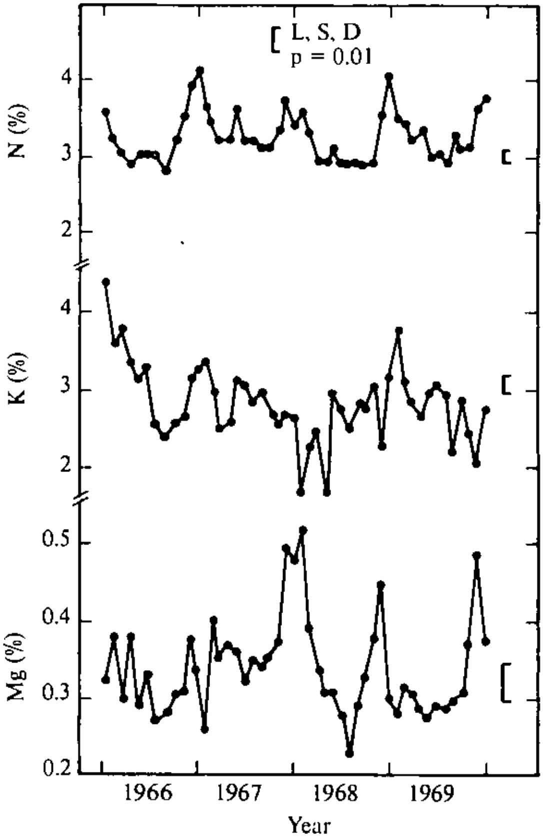


Fig. 11. Mean concentrations of N, K and Mg (% d. w.) in the third lamina of medium sized banana plants. Ten plants were sampled each month for 4 years *[96]*.

cult to assess nutrient concentrations experienced by the root. Methods of flowing nutrient culture have not yet been used for banana experiments. For 'Dwarf Cavendish' in Israel, K concentration in the leaf lamina was directly proportional to nominated concentration in the nutrient solution *[42]*. For 'Williams' cultivar in New South Wales the rectangular hyperbolae describes the relationship for all nutrients studied *[99]*. In the field, the application of fertilizer to the soil would be expected to increase the concentration of nutrients in the solution around the roots, however, fertilizer addition does not necessarily result in a change in leaf composition *[2, 35, 36]*.

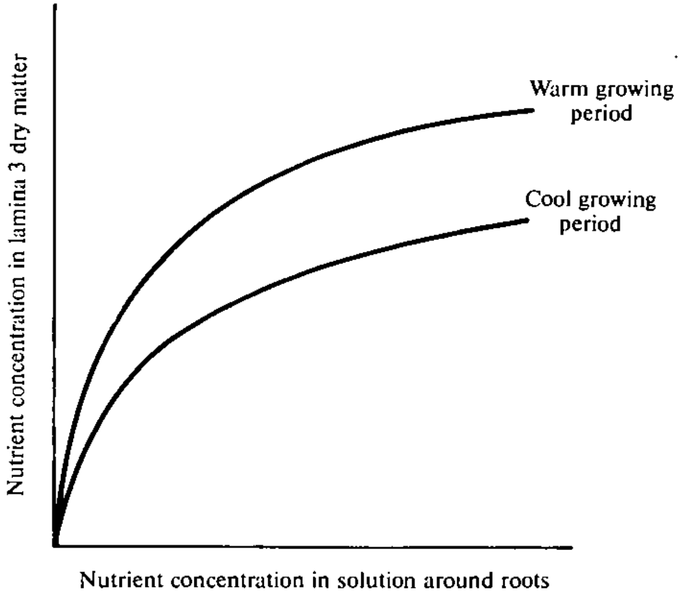


Fig. 12. Diagramatic representation of nutrient concentration in lamina 3 dry matter as influenced by concentration in solution around roots and seasonal conditions experienced by the sampled leaf *[99]*.

8.2 Plant analysis as a diagnostic tool

Because of the factors influencing nutrient concentrations, as discussed above, sampling technique becomes very important if comparable results are to be obtained. Standardization of sampling methods would be very useful although progress towards this goal has been slow *[64]*, partly because of the nature of the banana plant and partly because of the absence of unifying concepts concerning its nutrition.

8.2.1 Sampling methods

Sampling procedures have been investigated by many researchers *[15, 42, 66, 97, 104]*. Earlier work by *Hewitt [36]* in Jamaica defined some of the problems. *Martin-Prével [61, 64]* sought to bring a measure of uniformity to sampling methods by surveying the methods used in different countries (Figure 13). An international reference method (MEIR) was then pro-

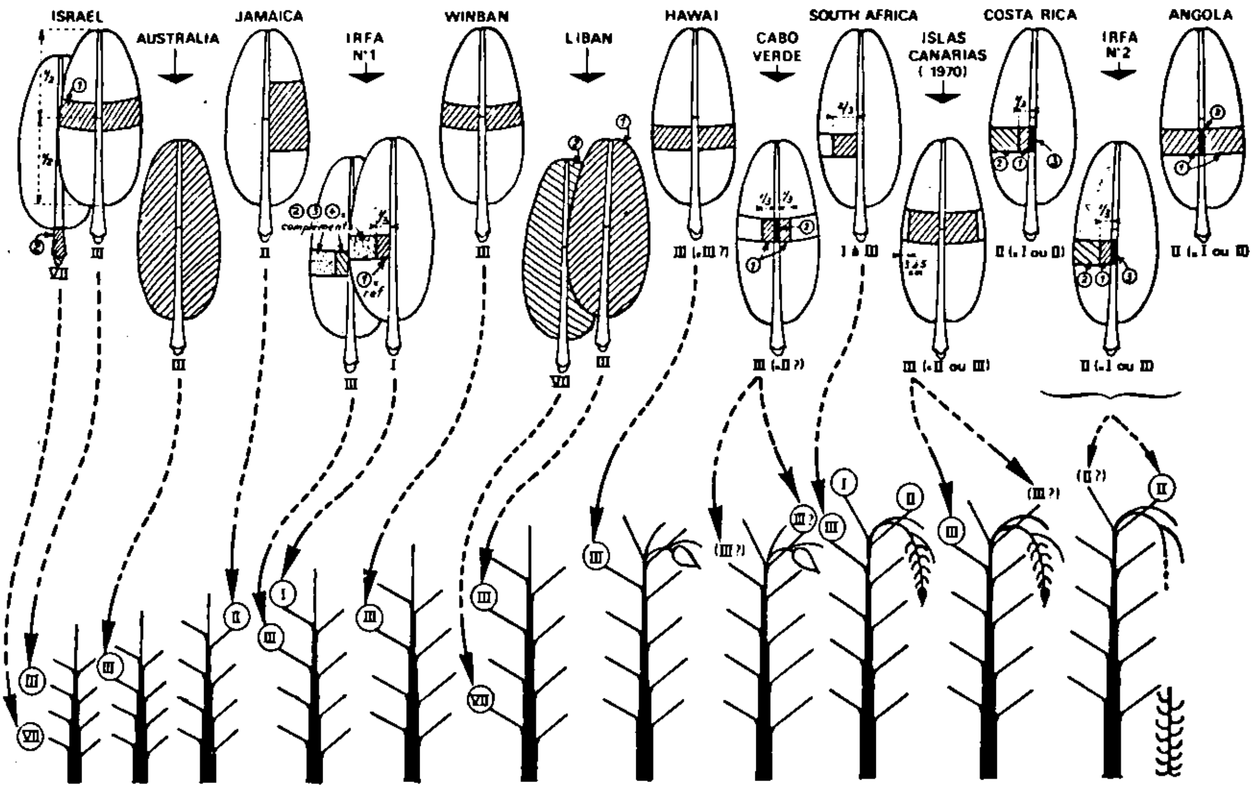


Fig. 13. Sampling methods used in various countries (after *Martin-Prével [62]*).

posed and agreed upon in 1975 *[62].* Three organs are sampled: lamina 3, midrib 3 and petiole 7 (Figure 14) in either large suckers or after the first hand of male fruit can be seen on the inflorescence. The MEIR method allows comparison of results between experiments but whether it is the best method for a diagnostic service still remains to be established. Recent developments in sampling methods and some of the unresolved issues have been reviewed in detail by *Martin-Prével [64],* who considers that the development of a uniform method of sampling has been slow, especially when the benefits are considerable.

For a diagnostic service, the appropriate sampling method is one which

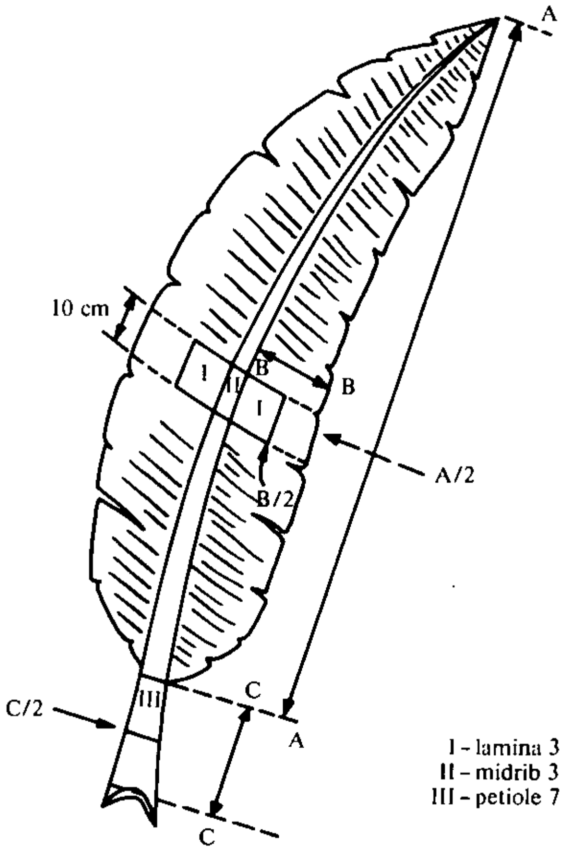


Fig. 14. Sampling procedure for banana leaves.

allows an empirical relation between the concentration of the nutrient and response to the application of that nutrient to be esablished. It may be that a single sampling method will not cater for all nutrients under all climatic and soil conditions *[43, 49]*. A full evaluation of the recommended sampling methods has yet to be completed but indications are that the petiole or midrib may be better than the lamina for assessing P status. Comparison of results between experiments is only possible where similar sampling methods have been used, although differences between some sampling methods may not be very great *[103]*.

A further requirement for a sampling method is that variation from plant to plant within a tissue is as low as possible. *Twyford and Walmsley [106]*, who sampled 10 plants, found that the usual diagnostic tissue used in the West Indies (the fourth leaf lamina) was the least variable for all elements and all other plant parts, especially at the "large" stage of plant growth.

As well as low plant to plant variation the concentration in the sample needs to reflect the nutrient status of the whole plant. This may be so with extreme deficiency *[78]* but under conditions more normally experienced in the field this relation may not hold. For example, *Twyford and Walmsley [106]* found that the concentration of K in the leaves (3.0%) or petioles (3.2%) at the "large" stage was the same for two sites in the Windward Islands but at one site the plant contained 210 g K and at the other only 108 g K.

A quantitative estimate of plant size, such as height, if used in conjunction with the concentration data, may give an estimate of whole plant nutrient content.

8.2.2 The setting of concentration standards

Many experiments have been conducted to establish the concentration of an element below which a response to added fertilizer may be expected *[2, 35, 36, 104, 112]*. The concentration below which a response can be expected varies with variety, sampling procedure and site. Standards for the interpretation of leaf analysis data have been established in a number of countries, based partly on experiment and partly on experience gathered over a number of years in a range of growing conditions. Tentative critical concentrations have been brought together in Table 14. These can be used within the constraints of variety, climate and local edaphic conditions.

Concentration standards are empirically derived and even within their own environment may not be very accurate. They do, however, provide a useful guide to the nutrition of a crop when considered along with other evidence such as symptoms, soil conditions and previous fertilizer history. This accounts for the widespread field use of leaf analysis in bananas.

Table 14. Tentative critical concentrations in the dry matter for the lamina 3, midrib 3 and petiole 7 at the "fully grown sucker" stage. (Mostly on the Dwarf Cavendish cultivar.)

Element	Lamina 3	Midrib 3	Petiole 7
N (%)	2.6	0.65	0.4
P (%)	0.2	0.08	0.07
K (%)	3.0	3.0	2.1
Ca (%)	0.5	0.5	0.5
Mg (%)	0.3	0.3	0.3
Na (%)	0.005	0.005	0.005
Cl (%)	0.6	0.65	0.7
S (%)	0.23	–	0.35
Mn (ppm)	25	80	70
Fe (ppm)	80	50	30
Zn (ppm)	18	12	8
B (ppm)	11	10	8
Cu (ppm)	9	7	5
Mo (ppm)	1.5–3.2	–	–
References	*36, 42, 57, 58, 78*	*42, 54*	*22, 42, 49*

Note: in lamina 3 the range of Al is 50–240 ppm.

8.2.3 Nutrient concentrations and crop performance

The use of nutrient concentrations in diagnosis of nutrient deficiencies is usually based on an assumed relationship between concentration and crop performance (growth or yield). Within any one experiment or group of experiments this relationship has been elusive except perhaps for the data of *Warner and Fox [112]* for Williams' banana in Hawaii. The relationship between N concentration in lamina 3 and yield for several experiments show a positive association between nutrient concentration and yield over all varieties, except that the Hawaiian data are displaced (Figure 15). *Warner and Fox [112]* achieved a wide range of nutrient concentrations and yield by using a continuous function approach in their experimentation. From their data they were able to establish a critical concentration of N in lamina dry matter.

8.3. Metabolic indicators

Leaf analysis is a technique which measures total nutrient element content and cannot distinguish between active and inactive fractions. This is especially important for elements such as iron. Several attempts have been made to find metabolic indicators for nutritional disorders in bananas.
Numerous metabolic indicators failed to be of practical value for the

assessment of the K-status of the sucker *[24, 42]*. $N-NO_3$ gives a more useful evaluation of the N-status of the plant than total N analysis *[51]*. In the lamina 3, 15–20 ppm $N-NO_3$ was suggested as being critical.

Organic and inorganic soluble P have been used to assess the P requirement of the plant *[63]*. This approach requires additional consideration and research before it can be used in practice.

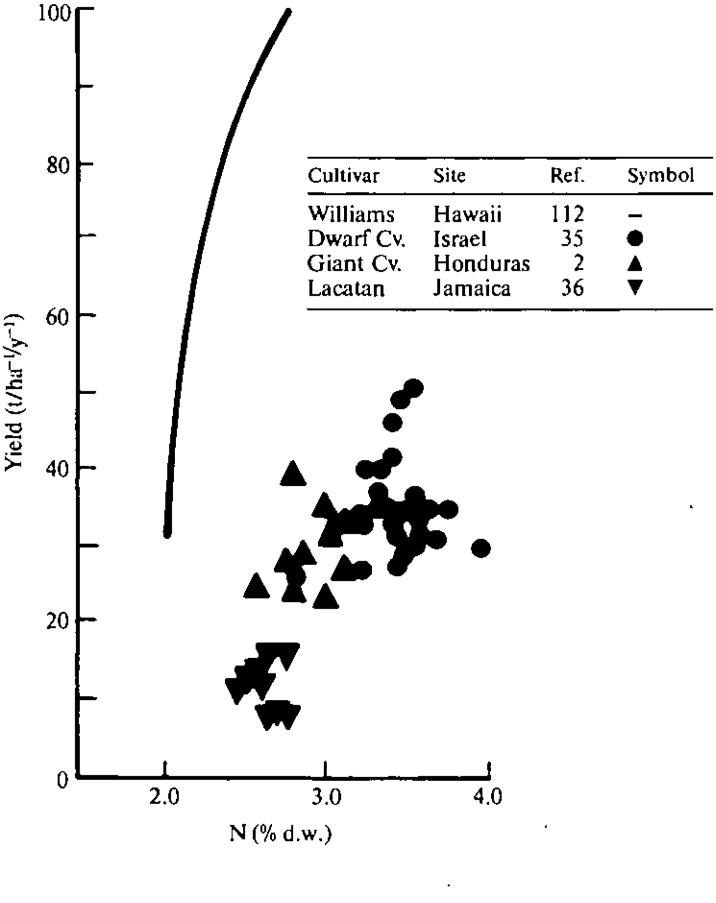


Fig. 15. Relationship between N concentration in lamina 3 (% d. w.) and yield, for several banana experiments *[2, 35, 36, 112]*.

9. Fertilizer practices and recommendations

The amount of N, P, K or other nutrients applied to a banana plantation to achieve high yields will differ from one location to another. What need to be born in mind is the large requirement for N and K, but this does not mean that these elements always need to be applied. For example, in the Jordan Valley, Israel, no K is applied but in the Coastal plain (only 50 km away) 1200 kg K/ha are applied annually. In this case differences in soil K supply dictate differences in K application rates.

Some countries provide fertilizer recommendations which, if followed, provide at least adequate nutrient supplies. However, actual practice within those countries varies significantly according to the climate, the variety being grown, the yield, the resources of the grower and his soil and management practices.

In Chapter 6, under each element, we have drawn attention to some commonly used fertilizer practices. Additional information with respect to N, P and K in different growing areas is presented in Table 15.

Table 15. Rates of N, P and K used in banana plantations in various countries (kg/ha/yr).

Country	Cultivar	N	P	K
Australia (NSW)	Williams	180	40—100	300—600
Australia (N. Territory)	Williams	110	100	630
Australia (Qld)	Mons Mari	280—370	70—200	400—1300
Canaries	Dwarf Cavendish	400—560	100—300	400—700*
Carribbean Is	Robusta, Poyo	160—300	35—50	500
Costa Rica	Valery	300	—	550
Honduras	Valery	290	—	—
India	Robusta	300	150	600*
India (Assam)	Dwarf Cavendish	600	140	280*
Israel (Coastal Plain)	Williams	400	90	1200*
Israel (Jordan Valley)	Williams	400	40	— *
Ivory Coast (Azaguie)	Grand Nain	110	—	190
Ivory Coast (Nieky)	Grand Nain	180	—	310
Jamaica	Valery	225	65	470
Taiwan	Fairyman	400	50	750

* In addition considerable amounts of manure are applied annually.

10. Acknowledgements

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